DOCUMENT RESUME

ED 267 998 SE 046 522

AUTHOR	Jones, Gordon E.
TITLE	Physics Demonstrations and Experiments for High School.
INSTITUTION	Mississippi State Univ., Mississippi State. Dept. of Physics.
SPONS AGENCY	Phil Hardin Foundation, Meridian, MS.
PUB DATE	85
NOTE	123p.
AVAILABLE FROM	Physics and Astronomy Dept., Box 5167, Mississippi State University, MS 39762. ($14.00)
PUB TYPE	Guides - Classroom Use - Guides (For Teachers) (052)
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	*Demonstrations (Educational); High Schools; *Laboratory Procedures; *Physics; Science Education; *Science Experiments; Science Instruction; *Secondary School Science

ABSTRACT

Presented are demonstrations and experiments that can be used by a variety of high school physics classes. The 131 demonstrations and 27 experiments were selected since they illustrate physical concepts clearly and directly, are simple to perform, and require a minimum of expensive or specialized equipment. Each demonstration and experiment is accompanied by a label, a (I) or a (II), which appears in the text after the title. A (I) designation indicates that the equipment or material required is particularly simple; it is not expensive nor does it require shop skills to build. Some of the demonstrations and experiments designated (II) require equipment that some high schools will not have. In many cases, however, the equipment can be constructed readily and inexpensively in the school shop. In addition, some of the demonstrations can be modified to avoid the need for equipment that is not on hand. The classification of an activity as a demonstration rather than an experiment, or vice-versa, is sometimes arbitrary. The individual teacher can best decide whether to perform it as a demonstration for the class or to let students perform it as an experiment. (JN)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

PREFACE

THIRD PRINTING

The demonstrations and experiments in this manual were performed by science teachers who participated in our two courses entitled "Demonstrations and Concepts for Physics Teachers." The descriptions found here are distillations of the writeups submitted by those participants.

Although some of these demonstrations and experiments were designed by members of the Physics Department at Mississippi State University and others were contributed by teachers in the course, most are not original. Many are well known and appear in some form in other manuals. Utility rather than originality was the main criterion used in selecting the demonstrations and experiments to be included. Specifically, the following considerations were made: (1) they should illustrate physical concepts clearly and directly, (2) they should be simple to perform, and (3) they should require a minimum of expensive or specialized equipment. In short, this manual contains demonstrations and experiments that are usable by a wide variety of high school classes, from those with minimal resources to those that are well equipped.

Each demonstration and experiment has been labeled by a (I) or a (II), which appears in the text after the title. A (I) designation indicates that the equipment or material required is particularly simple. It is not expensive nor does it require shop skills to build. Some of the demonstrations designated (II) require equipment that not every high school science class will have available. In many cases, however, the equipment can be constructed readily and inexpensively in the school shop. Some of the demonstrations can be modified to avoid the need for equipment that is not on hand.

The classification of an activity in the manual as a demonstration rather than an experiment, or vice-versa, is sometimes arbitrary. The individual teacher can

best decide whether to perform it as a demonstration for the class or to let the students perform it as an experiment.

It is not possible to thank all contributors to this collection; nevertheless, the efforts of Joe Ferguson and Jack Denson should receive special acknowledgement. They originated many of the demonstrations and experiments that are included here. In addition, special recognition should go to Robert Stockbridge, Jr. for the illustrations and to Kathy Stockbridge for typing and assistance with organization.

This project was supported by the College of Arts and Sciences of Mississippi State University and by the Phil Hardin Foundation.

Gordon Jones
Department of Physics
Mississippi State University
1985

TABLE OF CONTENTS

PART I - DEMONSTRATIONS

		Page
1.	Inertia	1
2.	Density	3
3.	Distance Traveled by Falling Objects	4
4.	Acceleration of Falling Objects in a Vacuum	4
4A.	Falling Objects and Air Resistance	4A
4B.	Weightlessness	4B
5.	The Effect of Horizontal Motion on the Acceleration of Gravity	5
6.	Projectile Motion	7
7.	Projectile Motion	8
8.	Projectile Motion	8
9.	Independence of Horizontal and Vertical Velocity Components	9
10.	Projectile Ballistic Cart	9
11.	Dependence of Acceleration on Mass	10
12.	Newton's Third Law	11
13.	Newton's Third Law and Conservation of Linear Momentum	11
14.	A Show of Strength	12
15.	Center of Gravity	13
16.	Centripetal Force and "Centrifugal Force"	17
17.	Direction of Velocity in Uniform Circular Motion	18
18.	Centripetal Force	19
19.	Noninertial Reference Frames	20
20.	Noninertial Reference Frames	20
21.	Tension in a String	21
22.	A Study of Tension and Acceleration	23
23.	Tension in a Horizontal String	24

24. Lever Arms 24

24A. The Torque Feeler 24A

25. Rotational Inertia 25

26. Rotational Inertia 25

27. Angular Momentum 26

28. Gyroscope 26

29. Tippy Top Effect 26

29A. Angular Momentum 26A

30. Conservation of Energy 27

30A. Conversion of Mechanical Energy to Thermal Energy 27A

30B. Pressure and a Bed of Nails 27B

31. Vibration of a Tuning Fork 28

32. Vibrations of a Spring and the Effect of Mass Change 28

33. Simple Harmonic Motion of a Tuning Fork 29

33A. Electromagnetic Display of Simple Harmonic Motion 30

34. Elasticity of Air and Damped Vibrations 31

35. Resonance of Tuning Forks 32

36. Resonance of Wineglasses 32

37. Resonant Vibrations in an Air Column 32

38. Resonance of a Spinning Rod 33

39. Film Loop: Resonance 33

39A. Force Vibrations 33

39B. Resonance of a Spinning Rod 34

40. Shatter a Wine Glass by Resonance 35

41. Air Tube Toy 36

42. Air Column Resonance 37

42A. Air-Column Resonance in a Paper Cup 38

42B. Standing Wave in a Straw 38

42C. Waveshapes 39
42D. Open and Closed Pipes 39
42E. Overblowing to Produce Higher Modes of Vibrations 39
43. Air Column Resonance 40
44. Resonance of Open and Closed Organ Pipes 40
45. Pressure Variations in a Column of Gas 40
46. Transverse and Longitudinal Waves on a String 41
47. Transverse Waves - The Wave Box 41
48. Constructive and Destructive Interference 41
49. Film Loop: Interference 42
50. Film Loop: Diffraction 42
51. Beats 43
52. Standing Transverse Waves on a Spring or Rope 43
53. Standing Waves on a String 44
54. Production of Two Different Waves 44
55. Laws of Vibrating Strings - The Guitar 44
55A. Harmonics on a Vibrating String 45
55B. Waveshapes of Vibrating Strings 45
55C. Shapes of Vibrating Strings 46
55D. Tone Quality of Plucked Strings 46
56. Effect of Wrapping Strings on Musical Instruments 47
57. The Audible Frequency Range 47
58. Sound as Pressure Variations 47
59. Propagation of Sound 47
60. Doppler Effect 48
61. Doppler Effect 48
62. Simple Reflection 48
62A. Properties of Reflections in Plane Mirrors 49

63. Real Image 50
64. Determining the Focal Length of a Concave Mirror 50
65. Image Formed by a Convex Mirror 50
66. Concave Mirror Used to Reflect Images on a Wall 50
67. Concave Mirror and Plane Mirror Used to Reflect Images on a Wall . . 51
68. Refraction and Reflection 51
69. Refraction 52
70. Focal Lengths of Lenses 53
71. Blackboard Optics 53
72. Demonstrations on Reflection, Diffraction, Interference and Refraction 56
73. Interference 57
74. Interference Patterns Thru Wire Screen or Cloth 57
74A. Refraction and Total Internal Reflection 58
75. Interference Fringes in Monochromatic Light 59
76. Polarization of Light 59
77. Absorption of Light 59
78. Fiber Optics and Total Internal Reflection 59
79. Color Subtraction with Sodium Light 60
80. Chair-Arm Demonstration on Color 60
81. Color Addition with a Color Box 60
82. Color-Addition Slide 71
83. Production of a Rainbow 61
84. Color Subtraction 61
84A. Viewing an Object Through a Pinhole 62
84B. The Blind Spot in the Human Eye 63
85. Positive and Negative Charge 64
86. Charging by Induction 64
87. Conductors and Insulators 64

88. Capacitors 65
89. Charging and Discharging Capacitors 65
90. The Ground as a Conductor 65
91. Magnetic Effects for Electric Current 66
92. The Magnetic Field Produced by an Electric Current 66
92A. Force Between Two Current-Carrying Wires 67
92B. A Simple Electromagnet 67
92C. Automobile Starter Solenoid 68
93. Magnetic Field of a Beam of Electrons 69
94. Magnetic Lines of Force 69
95. Construction of Electromagnet 69
96. Demonstration of the Strength of an Electromagnet 69
97. Magnetizing a Piece of Iron 70
98. Galvanometer 70
99. Electric Motor 70
100. Loudspeaker 70
101. Galvanometer to Show EMF Produced by Magnet 70
101A. The Generator Effect 71
101B. The Earth's Magnetic Field 71A
102. Armatures 72
103. Hand Turned Generator 72
104. Electromagnetic Effects 72

PART II - LABORATORY EXPERIMENTS

1. Measurements of Speed and Distance 73
2. Using Acceleration of Gravity to Calculate Reaction Times 73
3. Measurements of Height and the Acceleration of Gravity 74
4. Coefficient of Friction 75

5. Projectile Motion 77
6. The Scientific Method Applied to the Pendulum 79
7. Newton's Second Law on a Horizontal Plane 80
8. Newton's Second Law on an Inclined Plane 81
9. Estimation of Mass and Length 83
10. Acceleration of an Elevator 83
11. Equilibrium: Concurrent Forces 84
12. Equilibrium and Torque 85
13. Graphical Analysis of One-Dimensional Motion 86
14. Constancy of the Acceleration of Gravity 87
15. Centripetal Force 89
16. Resonance of a Closed Air Column 90
17. Thin Lenses 91
17A. Measuring the Size of a Distant Object using Geometric Optics . . . 92
17B. Interference and Diffraction of Light 93
18. Attractive Electrostatic Forces 94
19. Repulsive and Attractive Electrostatic Forces 95
19A. The Electric Field 96
20. Introduction to Electric Circuits 97
21. The Electric Circuit 99
22. Internal Resistances of Batteries 102
23. Ohm's Law 103
24. Plotting Magnetic Field Lines 104

PART I

DEMONSTRATIONS

1. INERTIA (I)

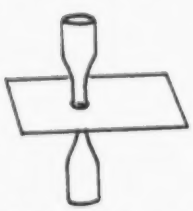
A. Place a stack of pennies on a table. With one separate penny, thump or slide this penny into the bottom penny in the stack. It should displace the bottom penny without knocking over the stack because of the inertia of the stack.

B. A nice trick can be demonstrated with a pill bottle, a pill, and two credit cards or playing cards. Place a pill on a credit card or piece of stiff paper. This is then placed on top of an open pill bottle with pill centered on the opening. Hold another credit card close to the bottom of the pill bottle so that it extends up past the other card with the pill. Hold this card in place with one hand and slightly bend it away from the bottle with the other card. Let go; the pill should remain at rest as the card flies off. The pill will then drop into the bottle.

C. (1) Tie one piece of string to the top of a weight and a piece of string to the bottom of the weight. While holding the top string and letting the weight hang, pull on the string with slowly increasing force until the string breaks. It should break above the weight, because there is more force on the top string (force of your pull plus the force of the weight). (2) Now retie the string and repeat the procedure, except this time pull with a very quick jerking motion. The string should break below the weight this time, because the inertia of the weight tends to make it stay in its original position.

(3) Tie one string to the bottom of the weight. Release the weight, then jerk the string. The inertia is such that, even while the weight is falling, the string breaks.

D. (1) Put paper under the base of a coke bottle that is sitting on a table and use a quick jerk to pull a strip of paper out from under the bottle.



(2) Turn the coke bottle on its mouth and repeat. (3) Put two coke bottles neck to neck with paper in between and jerk the paper.

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION
CENTER (ERIC)

✓ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY

Gordon E. Jones

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

INERTIA (continued)

E. A variation of the tablecloth demonstration can be done with the use of dollar bill and a lipstick. Have one-half of the dollar bill hanging over the end of a table. Place a lipstick on the other end. Hold the loose end with one hand and chop down with one finger between your hand and the table.

F. Place a large block of heavy metal on the hand of a volunteer as it rests on a table top. Strike the top of the metal hard with the hammer. The inertia of the metal absorbs the force of the hammer without hurting the person's hand. (This also demonstrates how the surface area is related to force and pressure.)

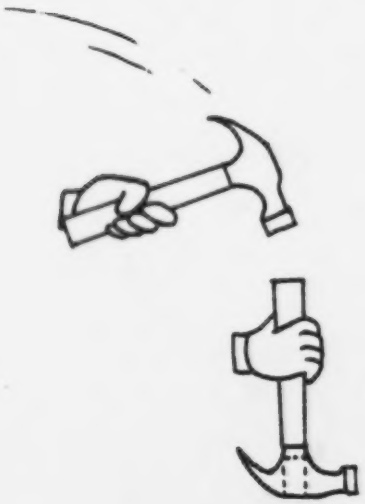
G. For a variation of the above, use a handkerchief or cloth, several bricks, and a hammer. Lay your hand palm-down on the table. Spread the cloth over your hand to avoid scratches from the rough bricks. Stack several bricks on the back of your hand. With a hammer, strike the top brick hard enough to break it. The inertia of the bricks will prevent damage to your hand.

H. Still another variation uses a hammer, nail, a soft wooden board, and heavy books. Let one student sit in a chair and hold the heavy block or books on his head. Put the board on top. Drive a nail into the board. The inertia of the board and books (or block) will absorb the blow and result in no discomfort to the student.

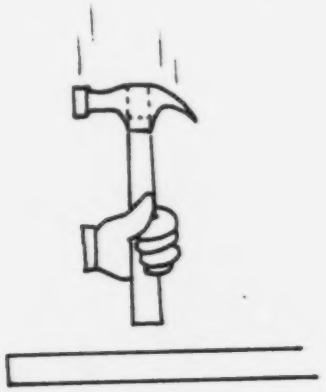
I. This demonstration uses two hammers, one with the head removed.

(1) Put the free head on the hammer just tight enough that it does not fall off when you turn it upside down. With a second hammer, drive the handle into the inverted head. The inertia of the head will allow you to drive the handle in tightly.

(2) Put the free head on the handle and keep it right-side-up. Bring the butt end down sharply on the table. The inertia of the head will cause it to be driven on tightly.



(A)



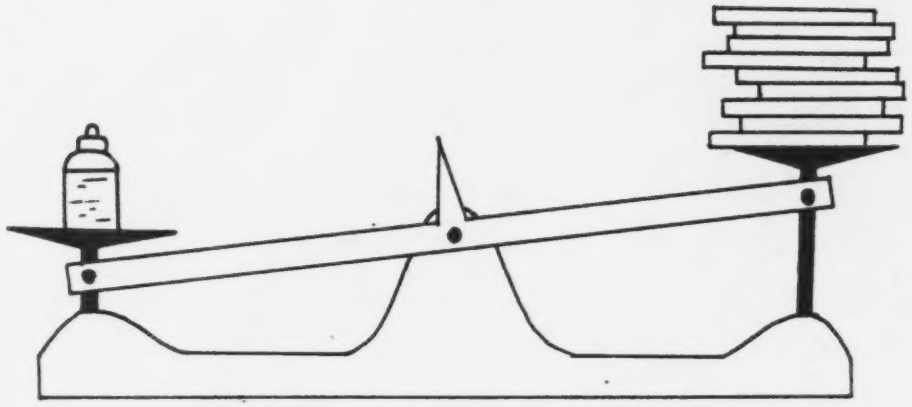
(B)

2. DENSITY (I)

Purpose: To illustrate the concept of density and to compare the densities of mercury and wood.

Materials: Small bottle of mercury, several 1" x 3" x 3" wood blocks, balance scale.

Procedure: Place a bottle of mercury on one side of a balance. Then add blocks of wood, one at a time to the scale until it balances. Because the density of mercury is so much greater than that of wood, it takes a surprisingly large number of blocks to balance the mercury.



3. DISTANCE TRAVELED BY FALLING OBJECTS (I)

Materials: Fishing line (about 10-12 feet), lead fishing weights, metal pan.

Procedure: Place the metal balls on the line in even intervals. Get above the metal pan and drop the entire string (stand on a ladder or on a safe table top.) Note the sound of the balls as they hit. Now, space the balls with the following distances between each one: 4.9 cm, 19.6 cm, 44.1 cm, 78.4 cm, 122.5 cm, 1.7 m, 2.4 m, and 3.1 m. Now drop this line and listen to the sound. Do the balls hit at the same time? Why? How many seconds apart do they hit the pan?

4. ACCELERATION OF FALLING OBJECTS IN A VACUUM. (II)

Materials: Vacuum pump with hose, glass vacuum tube chamber containing a feather (or piece of tissue paper 1" by 1") and a small wooden ball or metal coin. (These two objects are permanently sealed in the glass tube.) This equipment is available commercially. It can be made in a shop, but caution must be used, as the glass must be strong enough not to shatter when the air is removed.

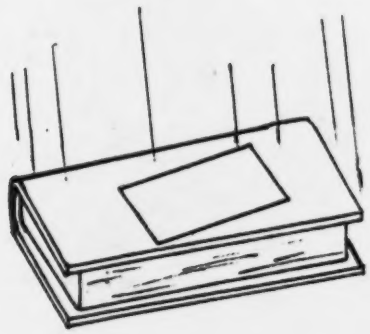
Procedure: The tube is initially filled with air. Rotate and flip the tube upside down. Observe that the coin falls faster than the tissue. Use a vacuum pump to draw the air out of the tube. Flip the tube upside down. This time the two objects fall at almost the same rate.

4A. FALLING OBJECTS AND AIR RESISTANCE* (I)

Materials: A book and a piece of unfolded paper (8" by 10" is fine).

Procedure: Hold the paper and book, one in each hand, at an equal height above a table. Ask the class, "If I release these two objects, which one will have the greater acceleration?" After the class guesses that the book will have greater acceleration because of air resistance, lay the paper on top of the book and release them. They will accelerate at the same rate.

*Credit to D. Rae Carpenter and Richard B. Minnix, Virginia Military Institute, Lexington, VA.



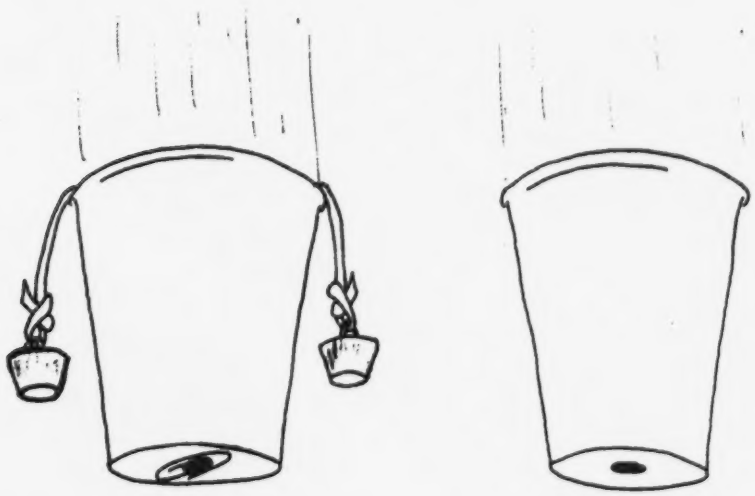
4B. WEIGHTLESSNESS* (I)

Materials: Two paper cups, 2 100-g weights, 1 large paper clip, 2 rubber bands, water, a water-proof trash can.

Procedure: Punch a hole the size of a pencil in the bottom of a paper cup. Attach a large paper clip to two rubber bands and place this against the hole on the outside of the cup. Run the rubber bands through the hole and attach a 100-g weight to each one. Stretch the rubber bands until the weights hang over the cup rim opposite each other at the top of the cup. Choose rubber bands that are not strong enough to pull the weight back over the rim into the cup. Stand on a table, hold the cup high, and let it fall. In free-fall, the weights become "weightless," and the rubber bands can easily pull them into the cup.

Punch a similar hole in the bottom of the second cup. Put your finger over the hole and fill the cup with water. While standing on the table, remove your finger and show that the water runs out. When you release the cup (allowing it to fall into a trash can), the water becomes "weightless" and the stream of water from the hole stops. Viewers do not have long to see this and must be told what to look for. The effect is more obvious if the cup is dropped from a high window onto the ground.

*Credit to D. Rae Carpenter and Richard B. Minnix, Virginia Military Institute, Lexington, VA



5. THE EFFECT OF HORIZONTAL MOTION ON THE ACCELERATION OF GRAVITY (I)

Purpose: To demonstrate that the acceleration due to gravity does not depend on horizontal velocity.

Materials: Electromagnet solenoid assembly (can be ordered from Bowie Audiovisual Enterprises, Inc., P. O. Box 867, Ridgeland, MS, Attn: Andre Landrum.), one dart gun with dart, 6-V DC power source, two 10-ft. pieces of lead wire with alligator clips, two pole stands with clamps, several thin strips of aluminum foil, a small jar top, one no. 8 one-hole rubber stopper, masking tape.

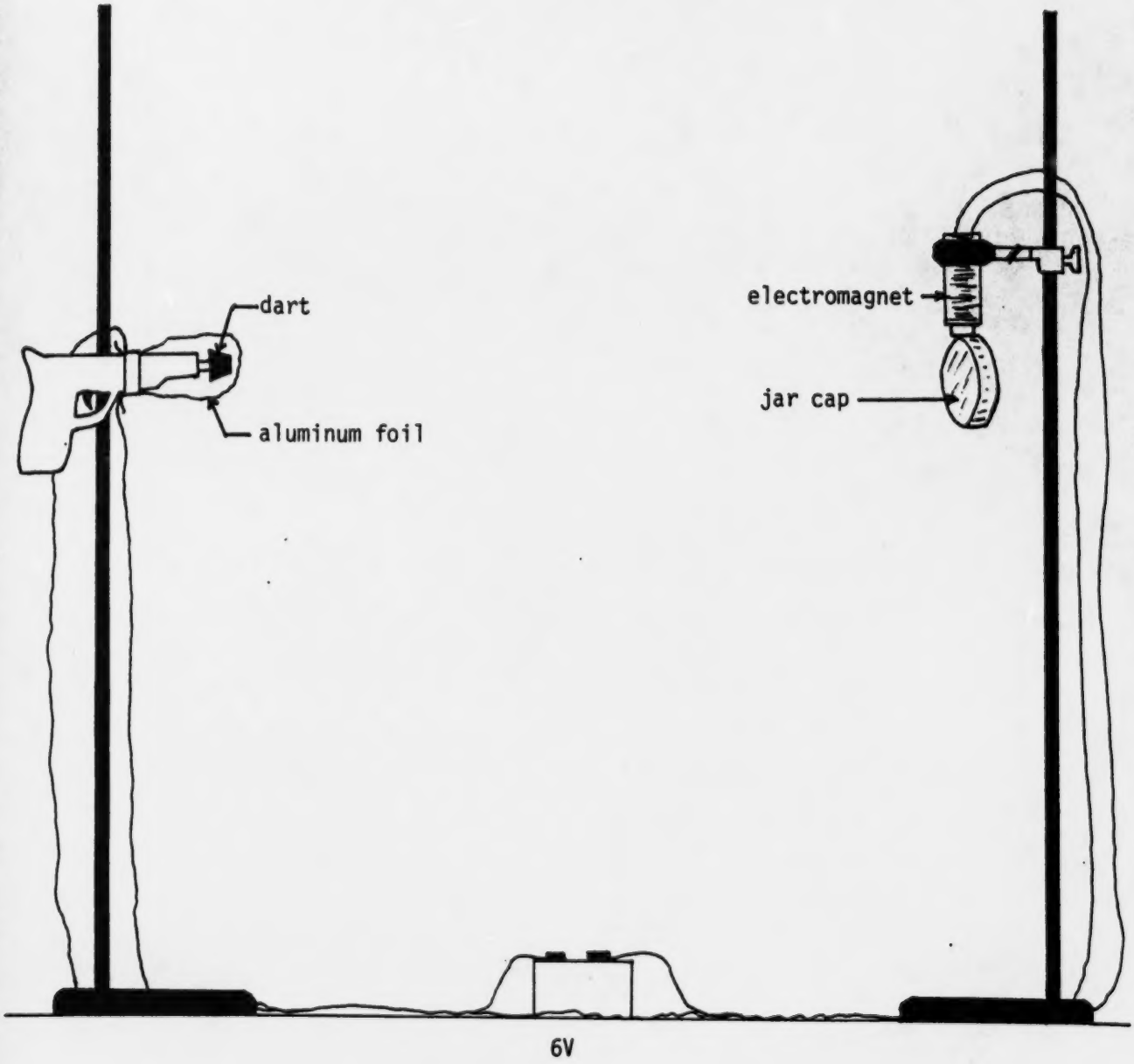
Procedure: This can be used as a demonstration or a hands-on experiment by students.

Attach the electromagnet to pole clamp. Run one lead wire from the electromagnet to the 6-V power source. (Batteries or a d.c. power supply.) Run another lead wire from the electromagnet to the dart gun, which should be clamped to the other pole clamp. Tape two small bare wires (1 to 2 inches long) on each side of the dart gun barrel. Attach the wire lead from the electromagnet to one of the wires taped on the side of the dart gun. Place the no. 8 rubber stopper on the end of the toy dart in place of the original rubber cup. (This will make the dart heavier and decrease its horizontal range.) Load the toy dart gun with the dart and run a thin piece of aluminum foil from one side of the barrel to the other side by wrapping it around the front of the rubber stopper on the dart. Attach the strip of foil to the pieces of wire taped on both sides of the barrel. Complete the circuit by running another wire from the side of the pole of the 6-V power source. The circuit is now completed.

Place the jar cap at the bottom of the electromagnet. The electromagnet should hold the cap in place. Adjust the height of the dart gun until it is at the same level as the jar cap. Aim the gun at the jar cap. The distance between the gun and jar cap should be about 6 feet. Fire the gun; as the dart leaves the muzzle it will break the aluminum foil, thereby breaking the circuit and releasing the jar cap at the same time. The dart should strike the jar cap in the air as it falls. This demonstrates that the dart and the jar cap are falling with the same acceleration. Move the gun farther away and try the demonstration several more times. If you miss, try using a thinner piece of foil. Ask students to answer the following questions:

1. What would be expected to happen if the jar top fell faster than the dart?
2. If the dart fell faster?
3. What does hitting the jar top with the dart prove?

(See diagram on following page)


dart
aluminum foil
electromagnet
jar cap
6V

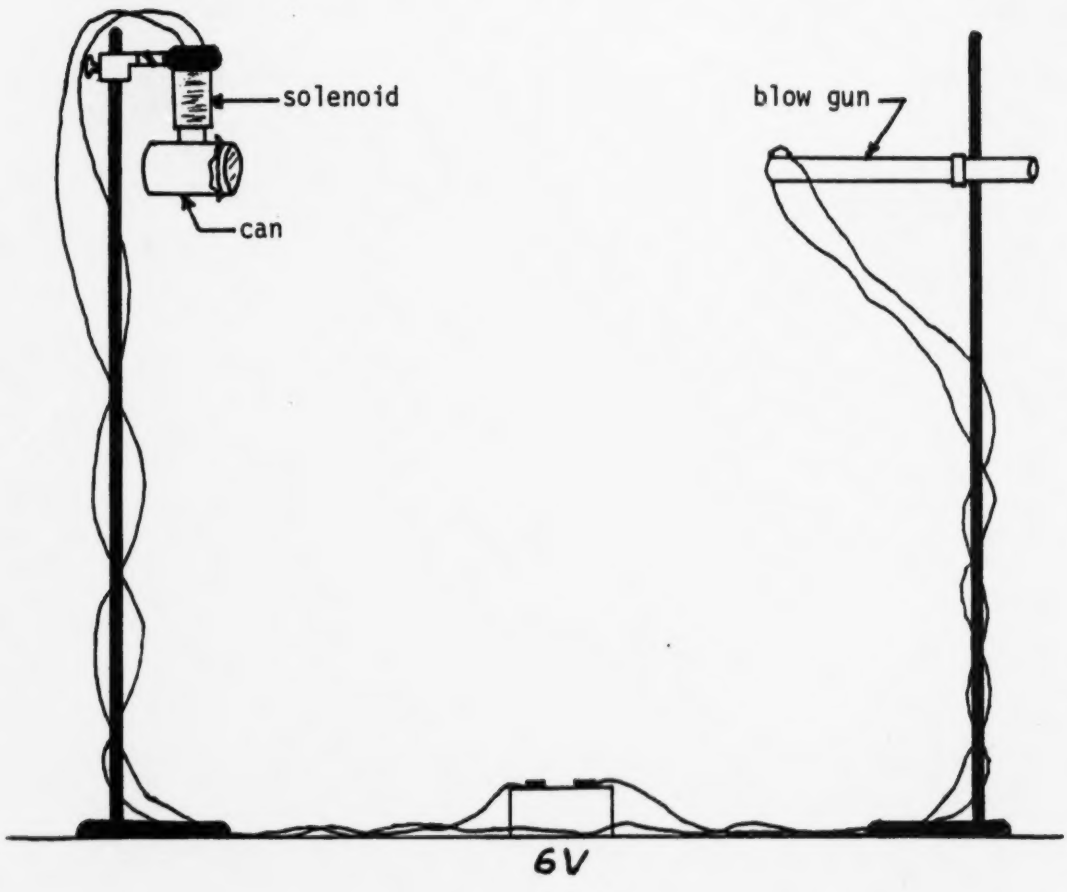
6. PROJECTILE MOTION (II)

Purpose: This is a variation of the previous demonstration.

Materials: Trajectory apparatus Cenco No. 75412-000 ($77.50) consisting of one metal blowgun, metal balls to fit the gun, and a solenoid. Also, wire, a 6-V power source (batteries are okay), clamps, ring stand, pole, a table clamp, and a metal can with the top removed.

Procedure: Fit the blowgun apparatus on table-clamped metal pole; make sure that the metal tip touches the gun. Mount the solenoid on a bar which is clamped to a floor stand. Line up the two structures about 8' apart. Wire a circuit from the blowgun to the solenoid.

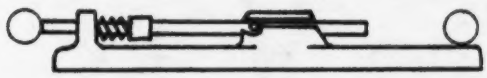
Load the gun with a metal ball and aim at the can. Turn on the power and blow a metal ball out the tube. As the metal ball hits the tip, it breaks the circuit, releasing the can. The ball should strike the can, as both fall at the same rate of acceleration. The ball pierces the paper and stays in the can, proving that the can was hit.



7. PROJECTILE MOTION (I)

Purpose: These two simple demonstrations illustrate the independence of horizontal and vertical components of motion.

Materials: Spring apparatus, "2nd law of motion apparatus" (Cenco No. 75345-000), two metal balls with holes in them, table clamp and pole, clamp.



Prodecure: Mount the apparatus at a convenient height for the students. Pull the spring to the tightest position. Position one metal ball on the metal rod and the other near the end of the shorter rod. Release the spring. One ball falls straight down, and the other is pushed off the surface to the side. Both land at the same time. Have students to stand back from the apparatus to see that both land simultaneously.

8. PROJECTILE MOTION (I)

Purpose: Same as above.

Materials: Two coins and a table.

Procedure: Place two coins on the table edge, one behind the other. Flip the back coin so that it glances off the other and goes flying off the table, thereby causing the front coin to drop off. Although one coin can have a greater horizontal velocity than the other, they will hit the floor at the same time, since only a vertical force is present on each coin.

9. INDEPENDENCE OF HORIZONTAL AND VERTICAL VELOCITY COMPONENTS (I)

Purpose: To illustrate the independence of horizontal and vertical motion.

Materials: One superball or golf ball.

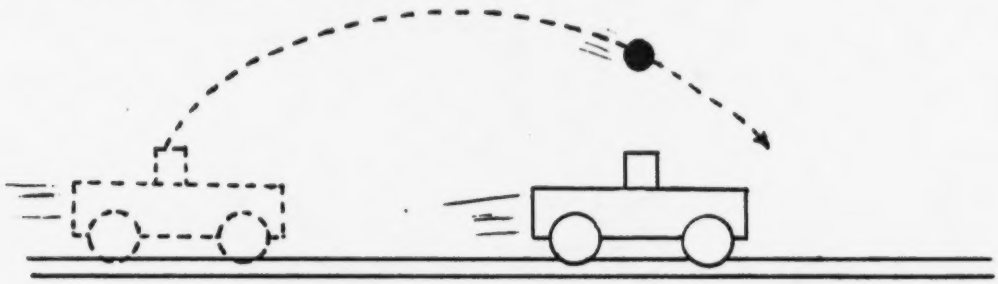
A. Procedure: Holding a ball in your hand at your side, release the ball while you are walking rapidly down a hall or across the room. The ball will keep bouncing beside you as you walk along. This demonstrates that the ball retains its horizontal velocity after you release it, and that the horizontal component is independent of its vertical motion.

B. Procedure: As a variation of the above, let the student walk rapidly across the floor and drop the ball so that it strikes a spot on the floor. Where does the student have to release the ball in order to hit the spot?

10. PROJECTILE BALLISTIC CART (II)

Purpose: To demonstrate the independence of vertical and horizontal motion.

Materials: Ballistic cart and a small ball.



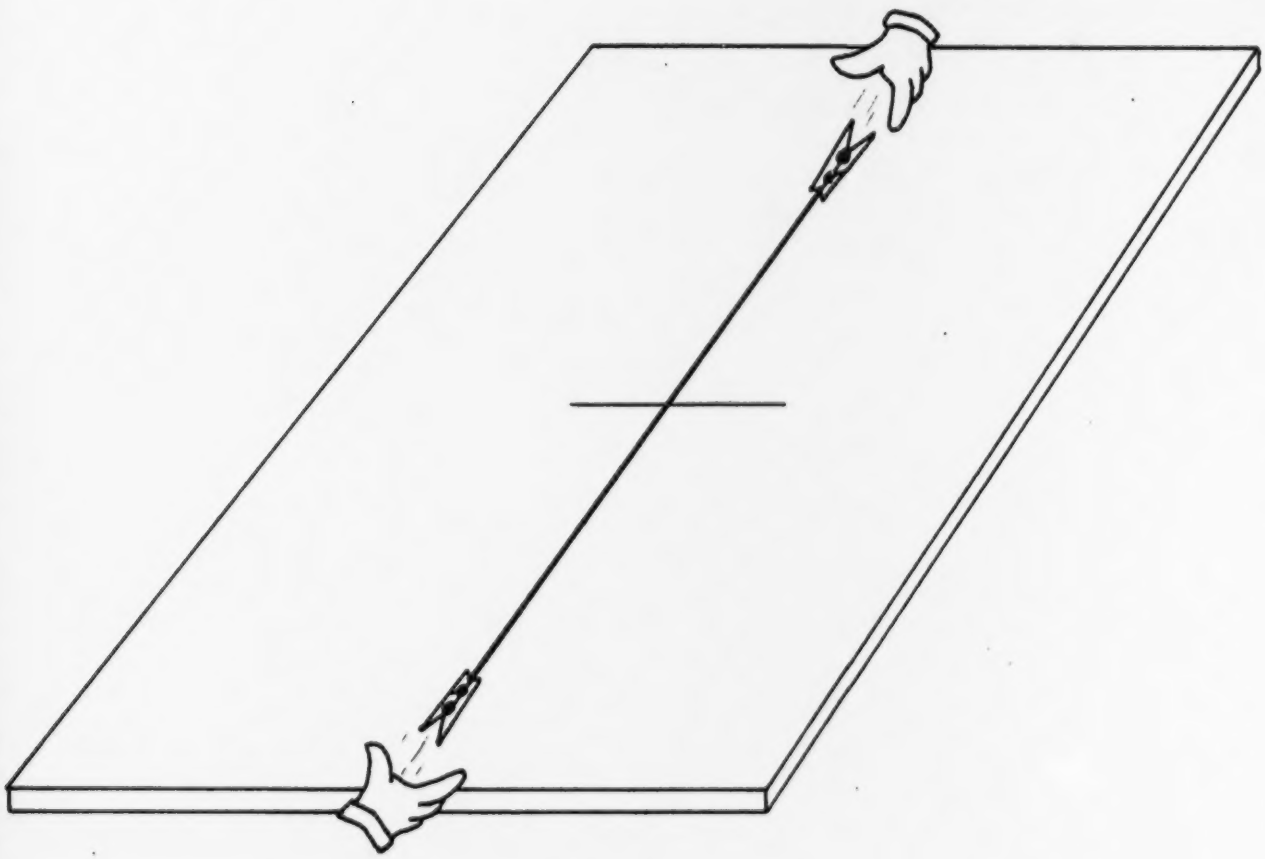
Procedure: The projectile ballistic cart is a car that projects a ball upward and catches the ball at a point further down the track. This illustrates that the x and y components of the forces are independent by demonstrating that the cart will not ride out from under the ball. The cart and track are available from Cenco, (75346-000) $58.50.

11. DEPENDENCE OF ACCELERATION ON MASS (I)

Materials: One weak rubber band, three or four clothespins, chalk.

Procedure: Select a surface, such as a table top, that can be viewed by all students. Make a chalk mark on the table. Cut the rubber band and make a chalk mart at its center. Clamp a clothespin onto each end of the rubber band. Holding the clothespins, stretch the rubber band and position it such that the mark at its center coincides with the mark on the desk. When the clothespins are simultaneously released, they should collide at the chalk mark on the desk. The forces on the clothespins are equal. Since the masses are equal, the accelerations are equal.

Repeat after attaching a third clothespin to one of the original two. The mass of one end is doubled, and its acceleration will be less. Let students predict where the clothespins will collide. Repeat for more clothespins.



12. NEWTON'S THIRD LAW (I)

Materials: A single large piece of paper, e.g., newspaper or butcher paper.

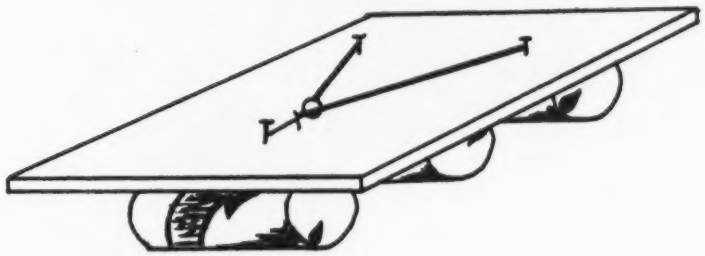
Procedure: Have two persons hold the paper unfolded and taut. Ask a big, strong student to use his fist to hit the newspaper with 50 pounds of force. (Or 25; or 10). Ask the class if he has succeeded.

The magnitude of the force of the paper on the student's fist is equal to that on the paper; it is obvious that the paper cannot exert 50 pounds of force on his fist. Ask the student if he would like to try when the paper is against the wall.

13. NEWTON'S THIRD LAW AND CONSERVATION OF LINEAR MOMENTUM (I)

Materials: 1 board (1" x 6" x 10"), 3 nails, 1 large rubber band, a steel ball or large glass marble, two empty soft drink cans, light string, hammer.

Procedure: Drive the three nails into the board in a V-configuration. Loop the ends of the rubber band around the two front nails. Tie a short piece of light string to the center of the rubber band. Stretch the rubber band and tie the string to the near nail. Place the marble in the "loaded" position.



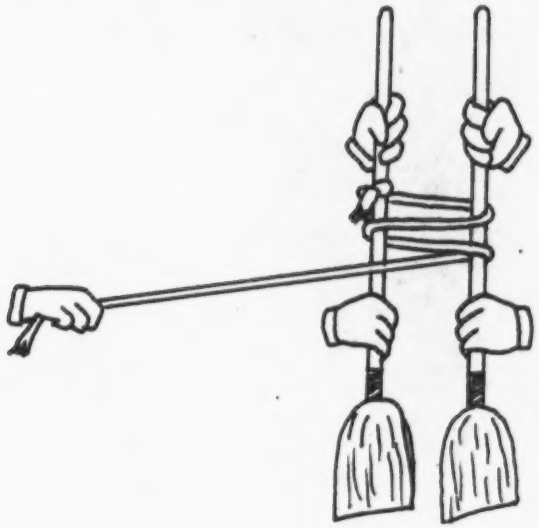
Lay the cans together on their sides and place the board on top. When the string is burned, the marble will be launched in one direction, and the cans and board will roll in the other.

14. A SHOW OF STRENGTH (I)

Materials: Two broom handles, a 4-m length of nylon rope.

Procedure: Choose two of the heftiest boys in the class and have them hold the broom handles perpendicular to the floor and about 20 cm apart. Tie one end of the rope (use a square knot) to one of the broom handles and weave the rope in and out around the handles as shown in the diagram. Choose a girl in the class to hold the other end of the rope.

Instruct the boys that when a signal is given, they are to pull slowly and steadily (as hard as they can in opposite directions) to force the broom handles apart. The girl will be expected to pull steadily on the rope in an effort to pull the handles together. Give the signal and let the contest begin. Who will win, the girl or the boys?

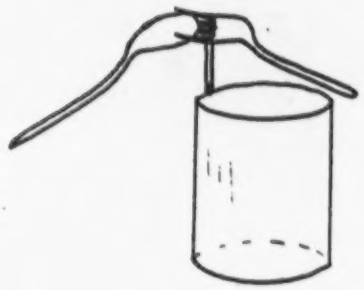


Answer: What has been done with the broom handles and rope is to form a combination of pulleys. The force pulling the broom handles together is increased as the number of turns of the rope are increased. It is similar to a block and tackle arrangement. The girl should have no trouble pulling the broom handles together.

15. CENTER OF GRAVITY (I)

A. Materials: Kitchen forks, glass, match.

Procedure: Insert the wooden end of a kitchen match between two tines of a fork, then insert a spoon between two other tines of the same fork. Balance this arrangement by the match on the edge of the drinking glass as shown in the diagram.

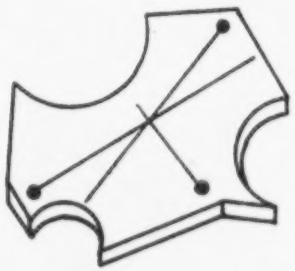


Ask the students if they know what will happen when the end of the match inside the glass is ignited with another match. At what point will the fork, spoon, and match cease to balance on the edge of the glass?

B. Materials: Two kitchen forks, one toothpick.

Procedure: Connect two forks by pushing their tines together. Place a toothpick between the two forks where their tines meet. Balance the toothpick on the tip of the underside of a student's fingernail.

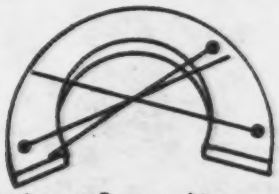
C. Procedure: Take an irregularly shaped piece of plywood and drill holes around the perimeter. Suspend the wood by a nail placed through one of the holes and attach a plumb line to it. Pop a carpenter's chalk line or draw a pencil line. Then suspend the wood from a different hole and repeat. Where the lines cross is the center of gravity (CG). A third line could be used to help verify the point. Drill a hole at the center of gravity and rotate the plywood about a nail driven into another piece of wood. Rotation about the CG occurs easily. Compare with rotation about another hole.



Two lines show where plumb bob lines crossed.

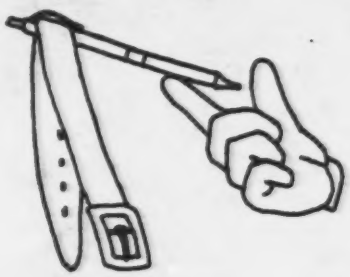
CENTER OF GRAVITY (continued)

D. Procedure: Repeat the same steps as above with a second board that has been cut so that the center of gravity lies outside of the board. Insert a stiff wire into the board so that it projects through the center of gravity. You can then suspend the board at its center of gravity on a nail that has been driven through another board.

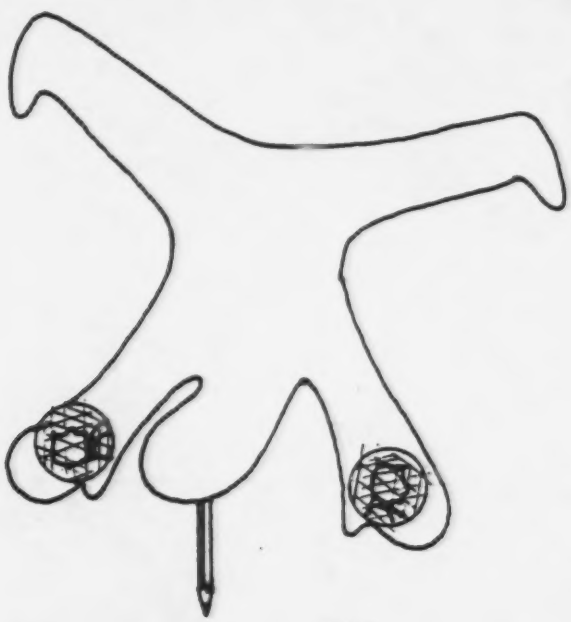


center of gravity

E. Procedure: Clip a belt approximately in the center to a ball point pen. You should be able to balance the system by supporting the end of the pen away from the belt on the tip of your finger. (Make sure the pen and finger are free of grease.)



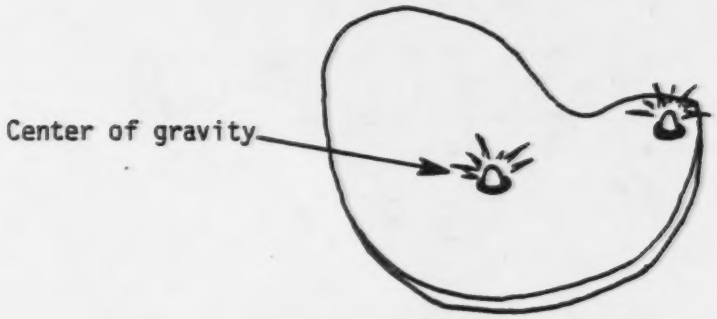
F. Procedure: Construct a clown out of cardboard in the shape shown below; attach a penny to each hand as counterweights. The clown will balance on its nose on the eraser of a pencil.



CENTER OF GRAVITY (continued)

G. Procedure: Use a bottle with a cork in it and place a straight pin vertically into the cork. Take a second cork and stick a needle into it at a vertical position; also, place three forks into the sides of the cork. By adjusting the forks slightly, you can balance the needle on the head of the pin.

H. Procedure: Find the center of gravity of a disk of styrofoam cut in an irregular pattern. Imbed a small flashlight bulb and battery at the CG. Place another light bulb (wired to the same battery) on the perimeter of the styrofoam disk. Connect each bulb to the battery imbedded in the disk. Throw the styrofoam upward with a spinning motion. The light at the CG has a simple motion. The light on the perimeter has a very complex motion.



I. Procedure: Get students to stand with their backs against the wall; put a dollar bill on the floor. Tell them if they can bend over at the hips and pick it up that they can have it.

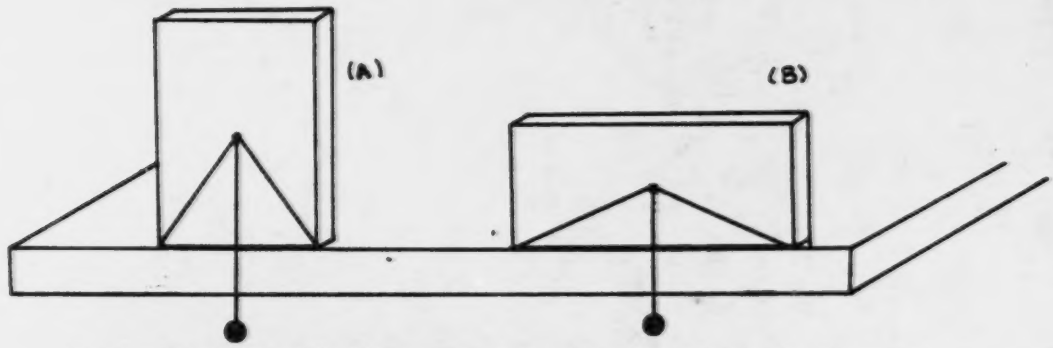
J. Procedure: Get students to stand with their right sides against the wall. Ask them to try to pick up their left feet. They fail because the CG is not over the supporting right foot.

K. Procedure: Get the biggest and strongest boy in the class to sit straight in a chair. Get the smallest, most petite girl in the class to place her finger on his forehead exerting enough pressure to prevent his leaning forward. The boy will be unable to get up, as he must be able to lean forward to shift his CG in order to rise.

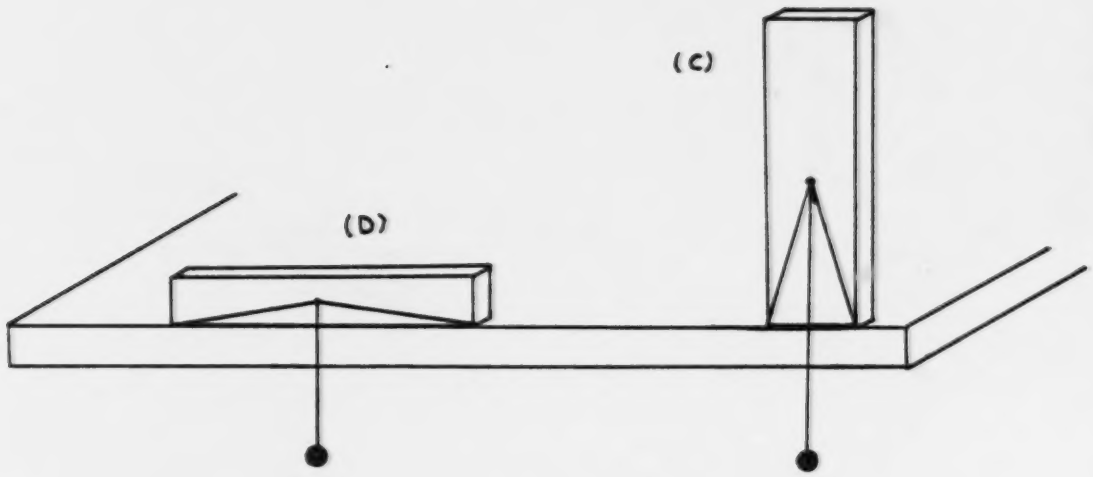
CENTER OF GRAVITY (continued)

L. Procedure: Put a chair against the wall; let the student stand in front of the chair. Tell him to bend over the chair, put his head almost against the wall, then try to lift the chair and to raise to an upright position. He cannot do so because of the location of his center of gravity. Let a girl repeat the procedure. Girls are often able to perform this, as they generally have lower centers of gravity. (This demonstration is not always successful.)

M. Procedure: Use the center of gravity concept to show that an object is the most stable when the CG must be raised in order to topple it. If a plumb tied at the CG crosses over the base of the object, it will topple.. A "two by four" block works nicely.



More effort (work) is required to tip the block in diagrams B and D, as the CG must be lifted higher. Therefore, these configurations are more stable.



Most stable

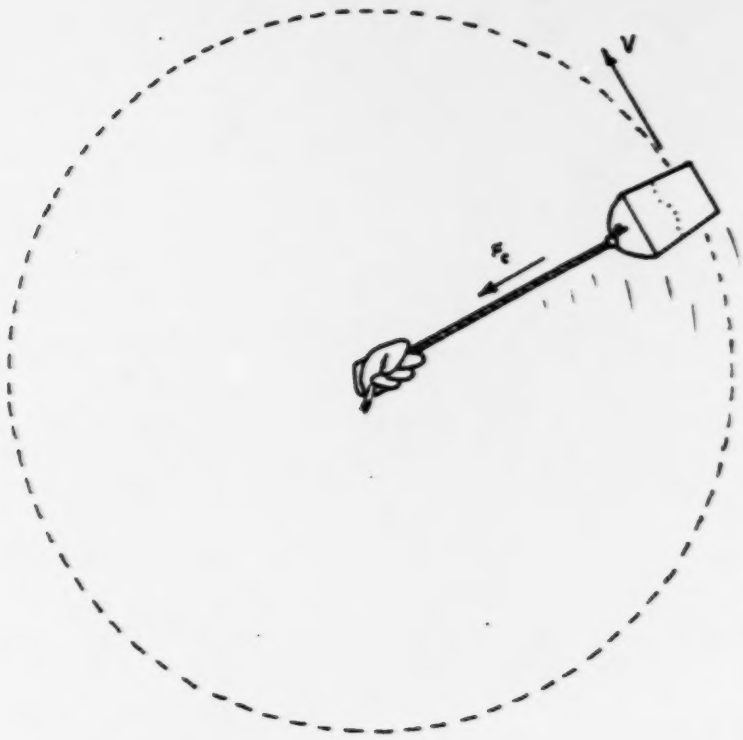
Least stable

16. CENTRIPETAL FORCE AND "CENTRIFUGAL FORCE" (I)

Purpose: To illustrate centripetal force.

Materials: One coffee can or small bucket with a handle and string attached.

Procedure: Fill the can about half full of water and whirl it in a circular motion with the plane perpendicular to the floor. The bucket undergoes a centripetal acceleration because your arm applies a centripetal force on it. The water remains in the bucket, not because of a force outward, but because its inertia tries to make it follow a path parallel to its velocity, which is a tangent to the circular path of the bucket.

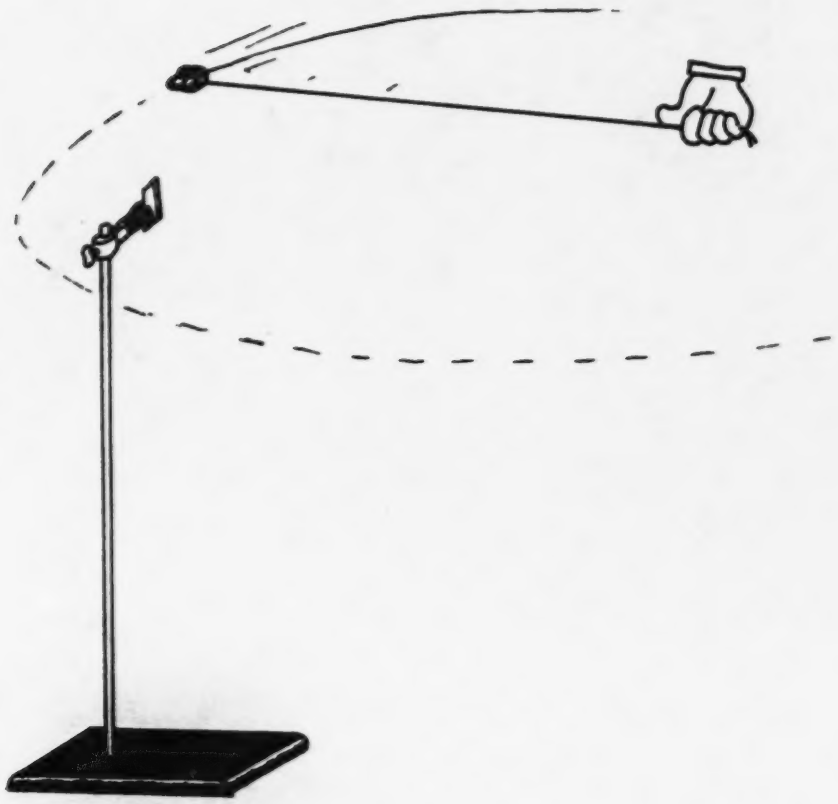


17. DIRECTION OF VELOCITY IN UNIFORM CIRCULAR MOTION (I)

Purpose: To show that the velocity of an object in uniform circular motion is tangent to the circle.

Materials: One razor blade, a pole stand with a clamp, string (about 3 feet), a small piece of balsa wood and a small piece of clay.

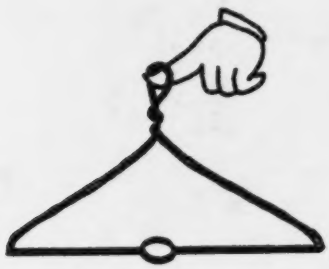
Procedure: Mount a razor blade vertically at the top of a pole stand. Tie the string to a small piece of balsa wood and mold a small clay ball around the balsa wood. While whirling the clay ball in a circular motion parallel to the floor and above the razor blade, slowly lower the plane of the circle to the razor blade. Whirl the ball until the string is broken by the razor blade. The ball should travel in a tangent to the circular path of the ball, since cutting the string removes the centripetal force which was accelerating the ball toward the center.



18. CENTRIPETAL FORCE (I)

Materials: A penny and a coathanger, hammered & filed flat in the center. Bend the neck of the coathanger into a closed loop.

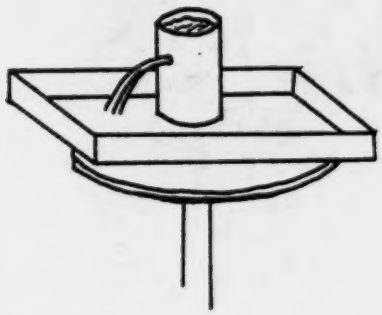
Procedure: Wet the index finger of one hand and place in the top of the coathanger as pictured below (this will make turning the hanger easier). Carefully place the penny on the flattened area of the coathanger. Gently rock the hanger back and forth a few times to give the penny an initial velocity. Then twirl the hanger about the index finger. The penny should stay in place until the coathanger slows down.



The penny stays on the hanger during the motion until it is slowed; then centripetal force is not sufficient to keep the penny moving in a circle.

19. NONINERTIAL REFERENCE FRAMES (I)

Procedure: Fill a can or some other container with water. The container should have an opening in the side so that a stream of water will flow from it. Set the can in a pan to catch the water and set this system on a stool that can be rotated. As the stool rotates, the stream of water is deflected in the opposite direction of rotation by "coriolis force." The point is that Newton's Second Law does not hold true in an accelerating frame of reference.



20. NONINERTIAL REFERENCE FRAMES (I)

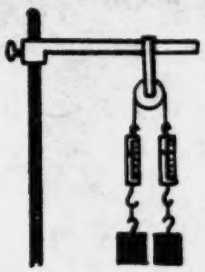
Procedure: Have every other student place a sheet of paper flat on his desk. Let his/her neighbor draw a pencil mark on the paper by moving the pencil at constant velocity. The forces cancel and the line is straight. Repeat the procedure except that this time the student whose desk the paper is on will rotate the paper while the pencil moves. From the frame of reference of the rotating paper, the line, since it is obviously curved, appears to have resulted from a force. The force is fictitious and appears because the reference frame is noninertial.

21. TENSION IN A STRING (I)

Purpose: To develop students' intuition regarding tension.

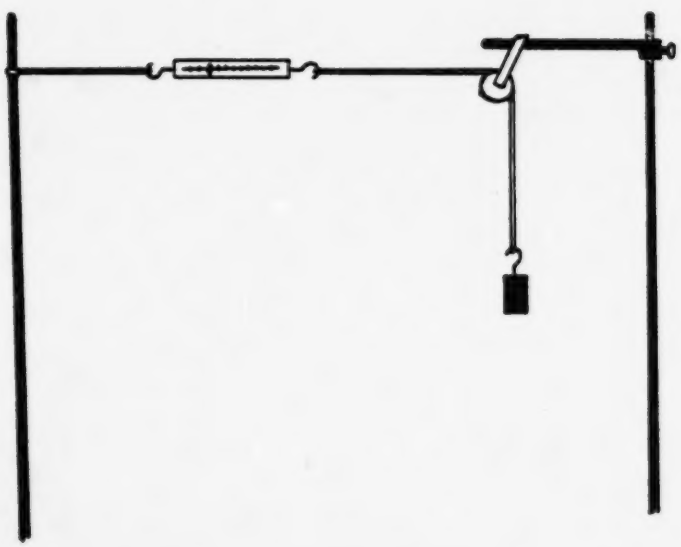
Materials: Two spring scales, string, two pulleys, two weights of equal mass, two poles with clamps.

A. Procedure: Attach two spring scales, top to top, by string. Run the string over a pulley and hang two equal weights, one on the bottom of each spring scale; note the readings on the scales. Both scales should read the weight of the hanging object. The tensions in the strings are equal.



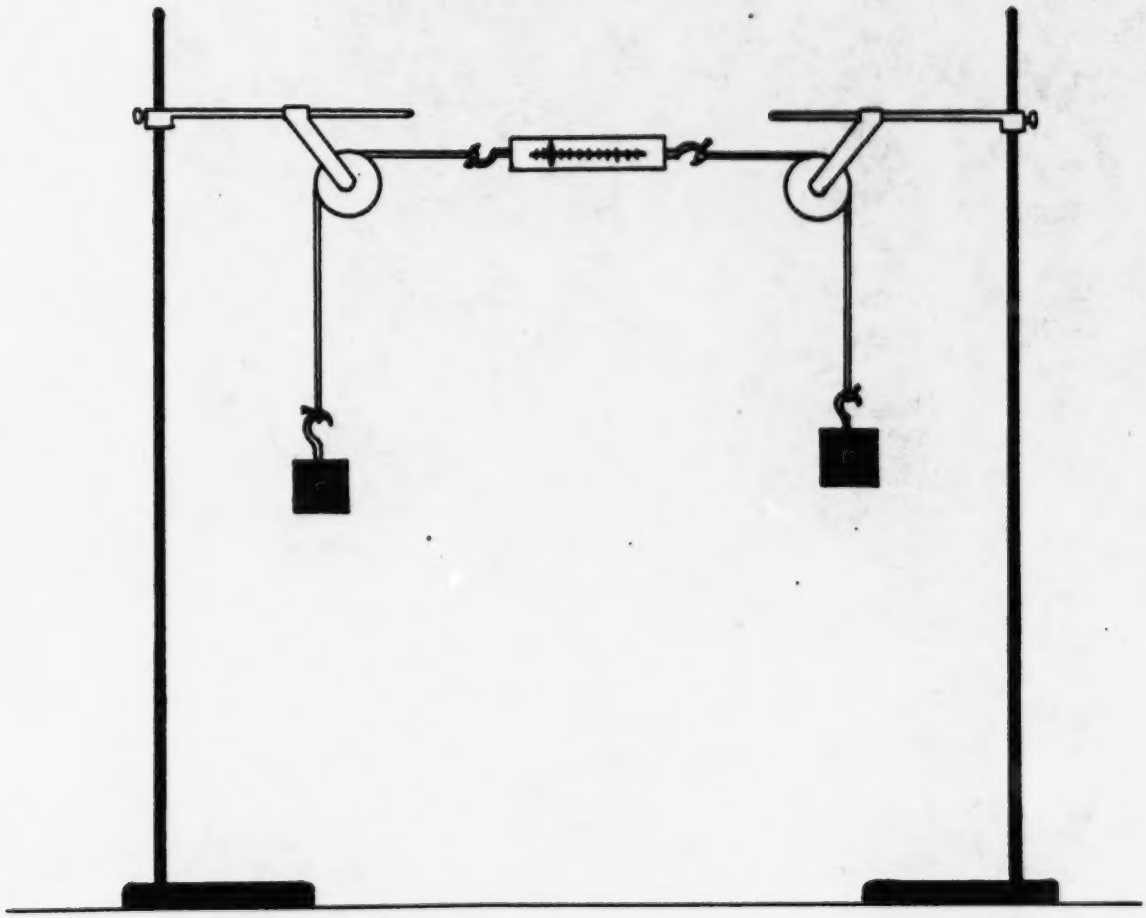
B. Procedure: Apply a downward force on one of the weights by gently pulling on it. Note the effect on the scale readings. The tensions remain equal. Now lay the string connecting the two scales over the top bar. Gently pull on one of the weights. This reading should increase while the other reading remains nearly the same (due to friction).

C. Procedure: Run a string horizontally from a spring scale attached to a rigid support to a pulley and then vertically downward. Attach a weight to the bottom end of the string. Note the reading on the spring scales. Ask, "what forces are working in the system?"



21. TENSION IN A STRING (continued)

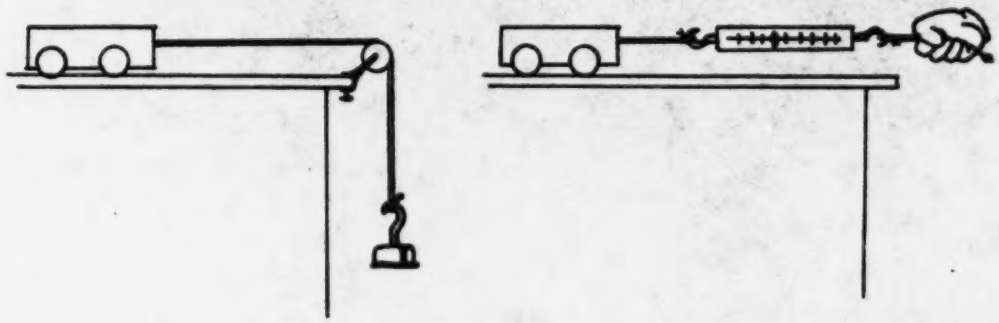
D. Procedure: Disconnect the top of the spring scale from the rigid support and attach a string to it. Run the string over another pulley and hang an equal weight on the bottom end of this string, as shown below. Ask students to predict the reading on the spring scale. What forces are acting in the system now? The scale reading is the same as above.



22. A STUDY OF TENSION AND ACCELERATION (I)

Materials: Weights, weight hanger, string, a pulley attached to a table clamp, stopwatch, spring balance, board.

Procedure: Compare the accelerations produced by the following two configurations.



Measure the times required for the object on the board on the table to accelerate one meter from rest. Calculate a from $d = \frac{1}{2} at^2$. This can be done as a demonstration or as a laboratory experiment with many trials.

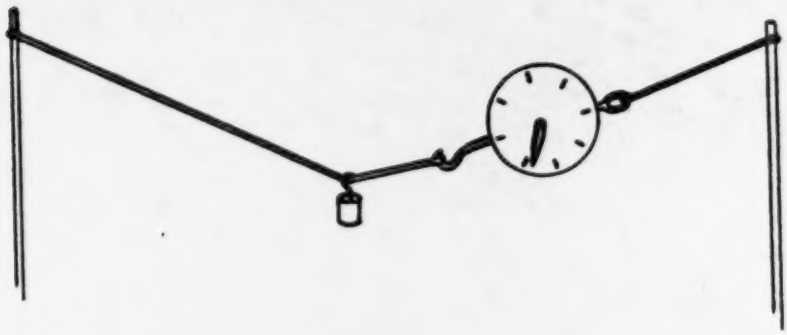
Experiment with the weights to find a combination which will work when pulled by a weight or by the same force by hand. For example, a 500-g weight is suitable for the "pulled" object and a 200-gram weight for the "pulling" weight. In the first part, the weights are attached by a string which just reaches from the 500-g weight at the beginning line down the board and over a pulley to the 200-gram weight. One person holds the 200-g weight and drops it on signal. The other person times the travel of the 500-g weight from the beginning to the ending line. In the second part of the experiment, one person pulls the 500-g weight over the same course while attempting to maintain a reading of 200-g on a spring balance. The other person measures the time it takes the 500-g weight to travel from the beginning line to the ending line.

Although some students will expect the accelerations produced to be equal, the tension that accelerates the weight on the table is greater in the second part of the experiment. (The tension in part 1 must be less than m_2g, or there would be no acceleration.)

23. TENSION IN A HORIZONTAL STRING (I)

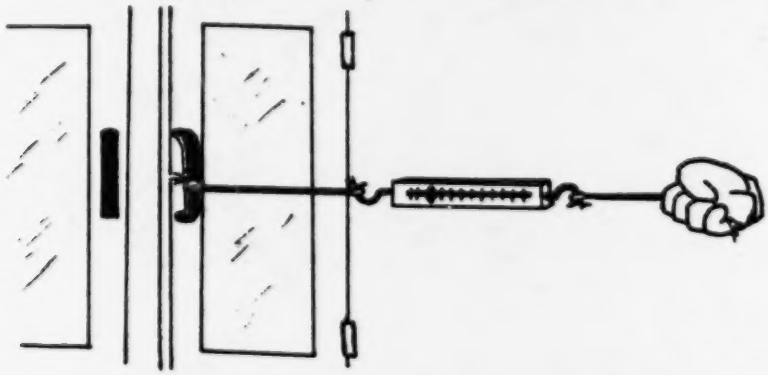
Materials: String, weights, spring scale, table stands.

Procedure: Suspend a spring scale horizontally between two poles. Put a 5-Newton force downward at the center of the string by suspending 500 grams. THe spring scale shows that the 5-Newton force produces a tension in the string that is considerably greater than 5 Newtons. Vary the amount of sag in the string and observe the effect on the tension. How can this be used to pull a stuck car out of the mud?



24. LEVER ARMS (I)

Materials: A heavy spring scale capable of recording several kilograms and a heavy door such as the entrance door to a public building.



Procedure: Open the door by pulling perpendicular to the door with the spring scale and note the reading on the scale. Now open the door by pulling at an angle of approximately 45° and note the reading of the force required to open the door. Explain that the torque required to open the door does not change. Since torque equals force times the lever arm, this product must be the same in both cases. If the lever arm is decreased, the force must increase to keep the torque the same.

Repeat for different locations of the spring scale and for various angles. Calculate the torque using the scale reading and angles and see if the torque is in fact constant.

24A. THE TORQUE FEELER* (I)

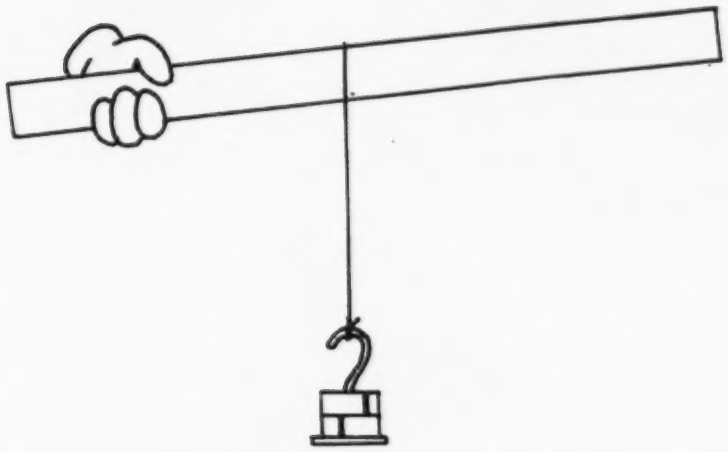
Materials: One meter stick, a meter stick clamp (to suspend a weight), a 1-kg weight.

Procedure: Hold the meter stick in your hand at the position 0-5 cm. Position the weight hanger at 10 cm and suspend the 1-kg weight. Notice the torque, which is evident in the ease with which the free end is raised and lowered as the stick is rotated about the hand position.

Move the weight hanger to the 20-cm mark and notice the increased difficulty in rotating the stick. Repeat at 40, 60, 80, and 100 cm.

The student may describe the sensation as an increase in "weight." It is the torque that is changing, as the weight is constant.

*Credit to Mary Beth Todd Monroe, Soutwest Texas Junior College, Uvalde, TX.



25. ROTATIONAL INERTIA (I)

Materials: Two 1½-meter lengths of 3-cm i.d. PVC pipe, eight rounded wood plugs or large rubber stoppers to fit snugly into pipe and lead shot.

Procedure: Put one kilogram of lead shot in the middle of one pipe. Put a plug all the way at each end to hold the shot in. In the second pipe, put one-half kilogram of lead shot at each end. Be sure they are equidistant from the ends. Use stoppers or plugs to position the shot. Mark the middle of each pipe. Now place your hand in the middle of the first pipe and rotate. the pipe rapidly. Repeat with the second pipe. One pipe resists rotational acceleration much more than the other.

Pipe 1

1 Kg lead shot

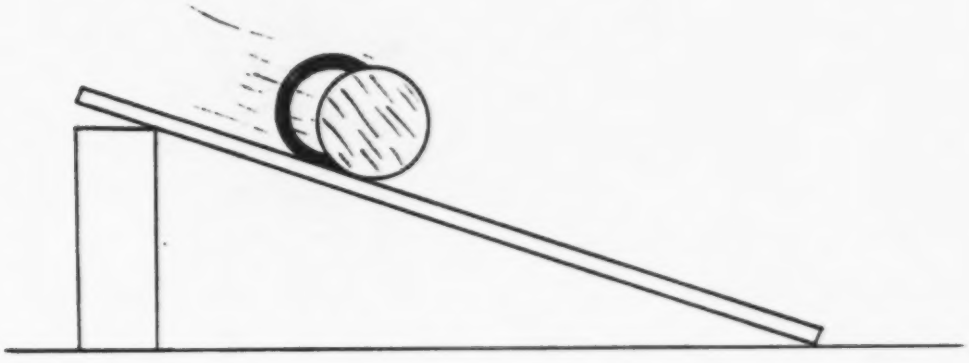
Pipe 2

1/2 Kg lead shot 1/2 Kg lead shot

26. ROTATIONAL INERTIA (I)

Materials: A wooden disk and a metal ring. (These are available from Cenco--Part No. 75255-000, $36.00); a long board.

Procedure: Prepare to roll the two objects down the inclined board. Ask which will get to the bottom first. Release the objects simultaneously and observe. Does the mass determine the winner? Does the radius?



27. ANGULAR MOMENTUM (II)

A. Procedure: Have a student sit on a stool that is free to rotate. His/her feet must be off the floor. (More convenient than an ordinary stool is one by Cenco -- 74792-000 for $52, or a rotating platform, Cenco -- 74790-000 for $240.) The student holds two heavy metal balls in outstretched hands. Turn the student and stool slowly. As the student brings the balls in closer to his/her body, the angular velocity increases.

This apparatus can be constructed in a machine shop using an automobile tire rim, axle, and brake assembly.

B. Procedure: Mount a bicycle wheel so that it rotates freely on an axis to which handles are attached. (Cenco -- 74786-000, $60.) Rotate the wheel rapidly and hand it to the student on the rotating stool. As the orientation of the rotating wheel is changed, the direction of rotation of the stool changes so that angular momentum remains constant.

C. Procedure: Suspend the rotating bicycle wheel by a string attached to one handle. The wheel remains upright and precesses.

28. GYROSCOPE (I)

Procedure: Demonstrate the action of a gyroscope. These are available from $6.00 up.

29. TIPPY TOP EFFECT (I)

Procedure: Turn a class ring (or other ring with a heavy smooth stone) down on a table and spin it (such that the plane of the ring is a vertical circle). The ring will immediately flip over and reorient itself with the stone on top. This "tippy top" effect is a result of the torque produced by friction.

29A. ANGULAR MOMENTUM* (I)

Materials: Two uncracked eggs, one hard-boiled and one raw.

Procedure: Spin the cooked egg on the table top. When it is spinning rapidly, stop it abruptly and then immediately remove your hand. The cooked egg remains at rest.

Repeat with the raw egg. When your hand is removed, the egg begins to spin again.

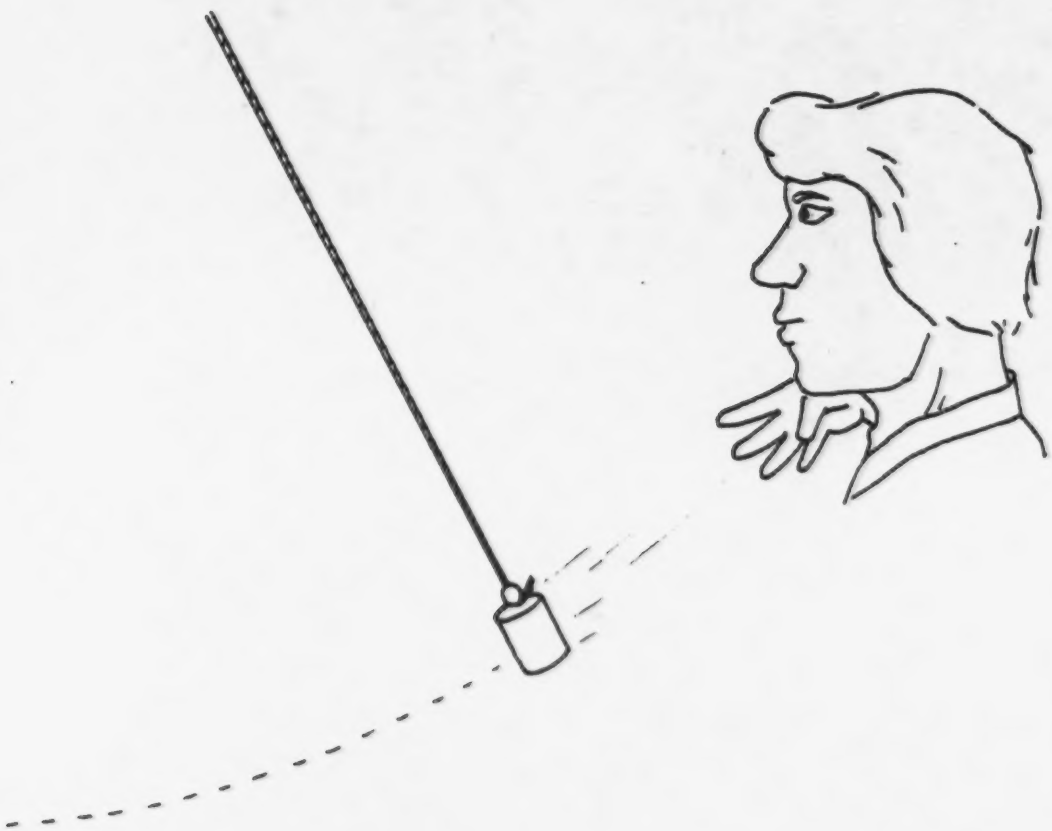
The liquid egg inside the shell was still spinning and imparted some of its angular momentum to the shell.

*Credit to D. Rae Carpenter and Richard B. Minnix, Virginia Military Institute, Lexington, VA.

30. CONSERVATION OF ENERGY (I)

Materials: Weight hanger, two or three 2-kg weights, cord, hook into ceiling.

Procedure: Make a long pendulum using the above materials and suspend it from the ceiling. Have a student release the pendulum from a position near her chin. If friction is low, the weight will return almost to the point of release. Have a contest to see if students can refrain from moving or blinking when the pendulum bob returns. (They should be careful not to push the weights when they release them.)



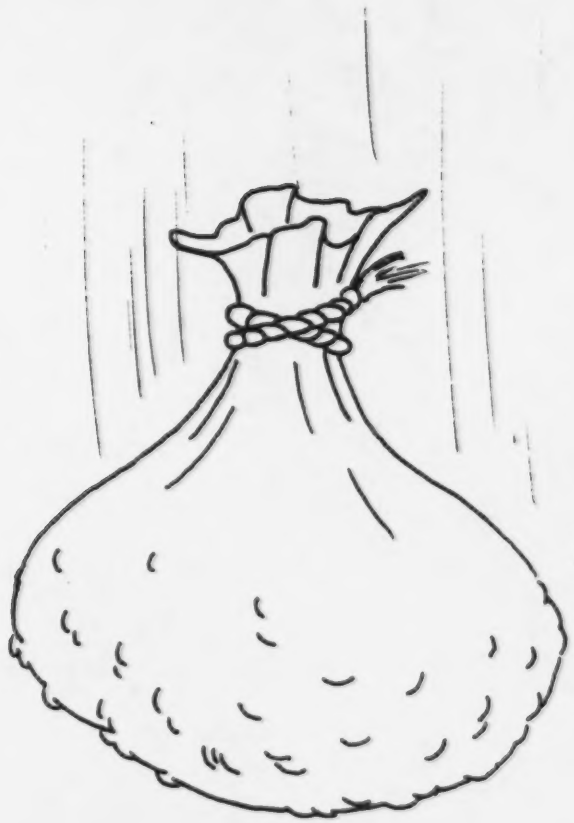
30A. CONVERSION OF MECHANICAL ENERGY TO THERMAL ENERGY (I)

Materials: Approximately 1 kg of lead shot, a heavy cloth bag, string, a thermometer with 0.1°C scale markings, a meter stick.

Procedure: Allow the shot to come to thermal equilibrium in the bag, and measure its temperature with the thermometer. Remove the thermometer and tie the bag securely. Drop the bag 10 times from a height of 2 meters onto a hard floor. Quickly open the bag and measure the temperature of the shot.

The conversion of gravitational potential energy into thermal energy is expressed by the equation $nmgh=mc\Delta T$, where n is the number of drops and c is the specific heat of lead (= 130 J/kg °C). Solving for the temperature gives $\Delta T = 0.0754\ nh$ (in °C). For ten drops from a height of 2 meters, this predicts a temperature rise of approximately 1.5 °C, assuming that all the thermal energy remains in the shot. Notice that the result does not depend on the mass.

Discuss reasons why your experimental result may not agree precisely with the prediction.



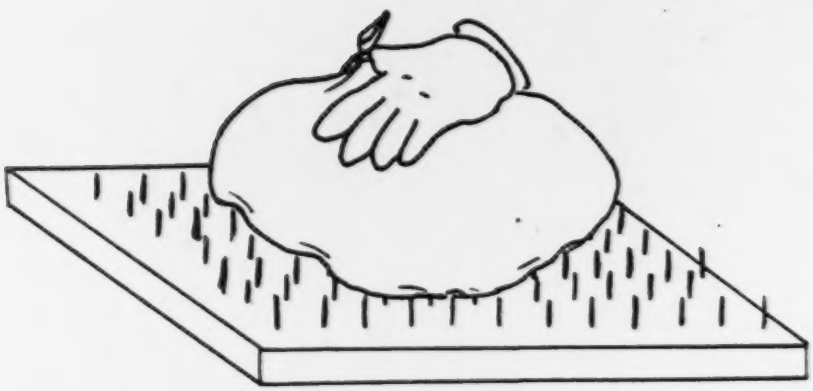
30B. PRESSURE AND A BED OF NAILS (I)

Materials: A balloon; a two-foot stepladder or chair; a wooden board or piece of plywood approximately 18 inches square with nails driven through; the spacing of the nails should be approximately 1/2 inch. The holes in the board should be drilled in order not to blunt the nails by driving.

Procedure: Place the board of nails on a sturdy table. The teacher or a volunteer then uses the stepladder to raise himself/herself above the board. The he/she sits down on the nails.

This does not hurt because the pressure is not great. The area of many nail points is sufficiently great that, even though the force is considerable, the pressure ($P = F/A$) is not.

Blow up a balloon and press it against the nails. It does not pop.



31. VIBRATION OF A TUNING FORK (I)

Purpose: To show that a sounding tuning fork is vibrating.

Materials: Tuning fork, beaker of water, towels, paper, overhead projector, and a flat dish.

A. Procedure: Strike a tuning fork. Stick it into a beaker of water. The vibrations will splash water out of the beaker. (Be prepared to mop it up.)

B. Procedure: Hold a vibrating tuning fork to a sheet of paper. The paper will vibrate noisily. Touch the vibrating fork to the chalkboard.

C. Procedure: Hold a vibrating tuning fork into a flat dish of water on an overhead projector. The vibrations will be seen as a ripple pattern on the screen. (When both vibrating tines are immersed, interference effects can be seen briefly.)

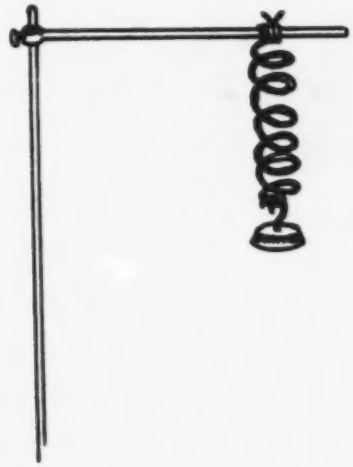
Tuning forks are available from Cenco p. 140, 1980 Cat. No. 84560-002-015. Approx. $8.00 each.

32. VIBRATIONS OF A SPRING AND THE EFFECT OF MASS CHANGE (I)

Purpose: To study the slow vibrations of a spring.

Materials: Stand, rod, spring, mass holder, and weights.

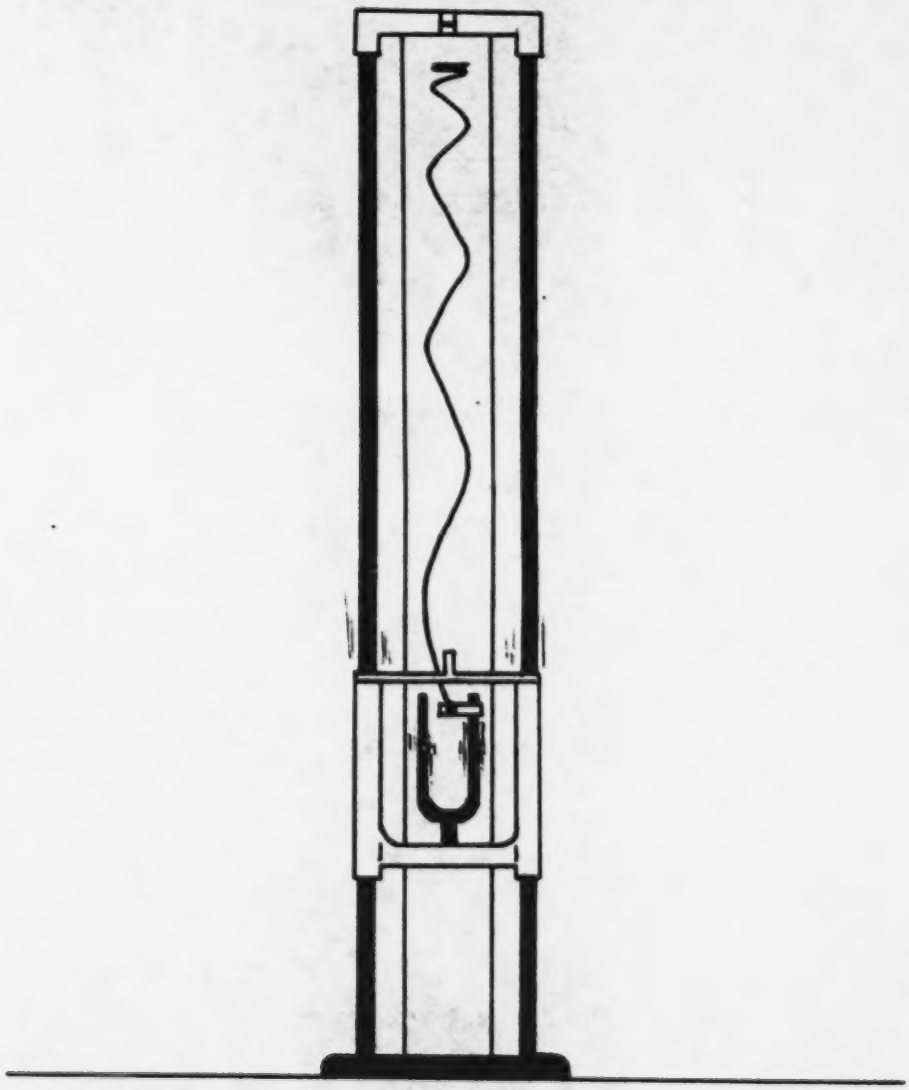
Procedure: Attach a mass as shown. Determine the approximate period and frequency. Discuss the restoring force, which causes the object to return to equilibrium. Point out that inertia carries the spring beyond equilibrium. Add weight and notice the effect on the period. More massive objects vibrate with lower frequencies. Lighter objects vibrate with higher frequencies.



33. SIMPLE HARMONIC MOTION OF A TUNING FORK (II)

Materials: One tuning fork and pen, vertical track (about five or six feet tall), tracking paper. (See Cenco.)

Procedure: Assemble a vertical track with a narrow strip of tracking paper attached. Attach a tuning fork to a weight, which can slide down the vertical track when released. Attach a pen to the stem of the tuning fork so that it comes in contact with the paper. Tap the tuning fork causing it to vibrate and release the weight with fork and pen attached. As the weight falls, the pen will trace the oscillations of the tuning fork on the paper, creating a wave pattern down the paper track. Observe this wave pattern. (The wavelength of the waves will become increasingly longer as the wave pattern goes from the top of the vertical track to the floor. The change in wavelength can be used to calculate the acceleration due to gravity if you know the frequency of the tuning fork.)



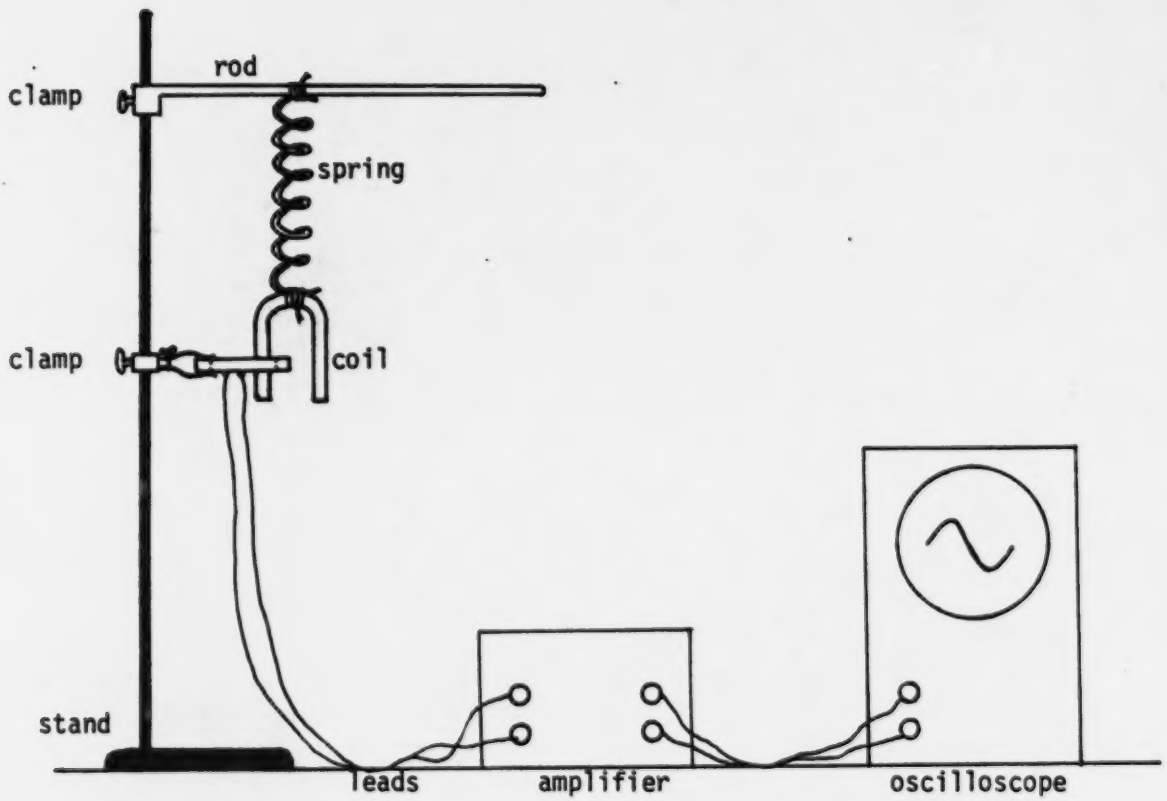
33A. ELECTROMAGNETIC DISPLAY OF SIMPLE HARMONIC MOTION (II)

Purpose: To use the emf induced in a coil by a moving magnet to prove that the small-amplitude oscillation of a spring is simple harmonic motion.

Materials: Toroid or coil of wire, amplifier, oscilloscope, horseshoe magnet, spring, stand, rod, clamps, clip leads.

Procedure: Suspend the magnet from the spring so that coil is positioned between the poles of the magnet. Use leads to connect the ends of the coil or toroid to the input of the amplifier. The output of the amplifier goes to the vertical input of the oscilloscope.

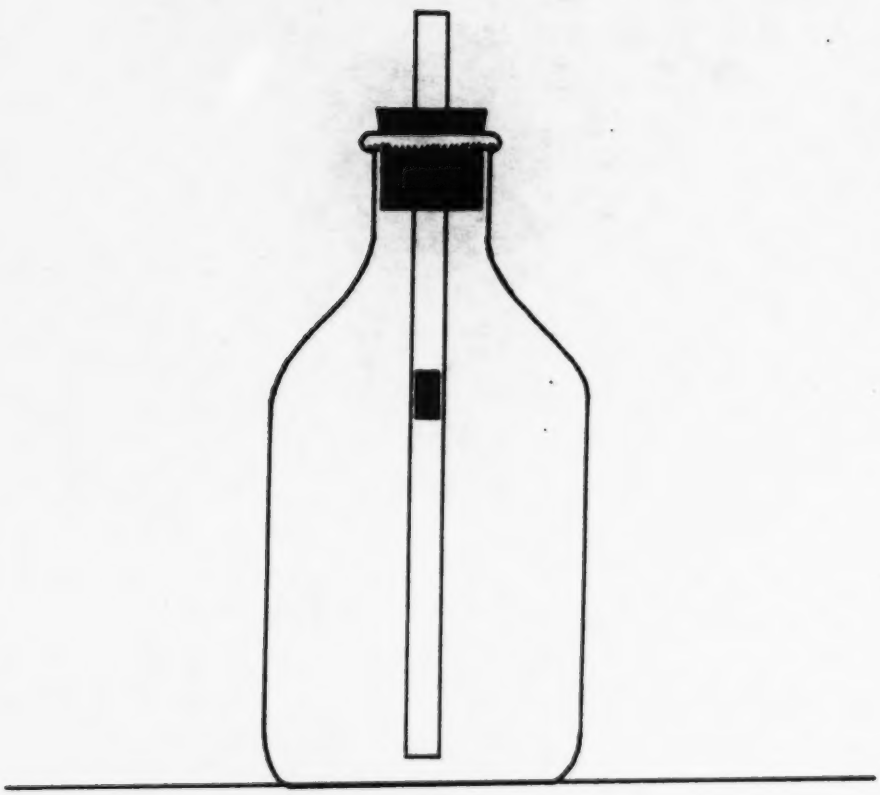
Displace the magnet slightly from equilibrium and let it oscillate with small amplitude. The emf induced in the coil will be displaced on the oscilloscope. If the motion is simple harmonic, the shape of the electrical signal will be sinusoidal.



34. ELASTICITY OF AIR AND DAMPED VIBRATIONS (I)

Materials: Tall bottle, one-hole stopper, clear glass tubing and a brass plug of about the same outside diameter as the inside diameter of the tubing. This may require precision glass tubing, as the fit must be close.

Procedure: Drop the plug into the tubing from the top. It will bounce up and down in the column until the energy is dissipated. This indicates that air is elastic.



35. RESONANCE OF TUNING FORKS (II)

Materials: Two tuning forks of equal frequencies, each mounted on a hollow box. (Cenco, No. 84570-000, $58.00)

Procedure: Strike one tuning fork and observe that the second tuning fork also vibrates. This demonstrates resonance. Add a weight or a clamp to one of the tuning forks. Striking one of the tuning forks this time will not cause the other one to vibrate, because the tuning forks no longer have the same natural frequencies.

36. RESONANCE OF WINEGLASSES (I)

Materials: Wine glasses of at least two sizes.

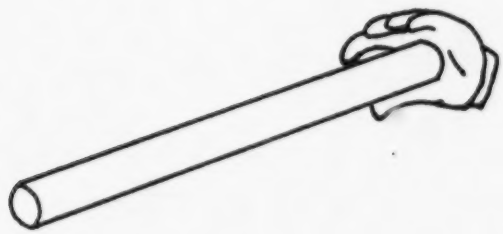
Procedure: Wet the rim of the glass and your finger. Rub around the rim with your finger. After fifteen or twenty seconds, the glass will "hum" as it vibrates. Different size glasses have different frequencies. Show the effect of using glasses filled with water to different levels.

37. RESONANT VIBRATIONS IN AN AIR COLUMN (I)

Materials: A conch shell or tube (metal, plastic, cardboard, etc.).

A. Procedure: Hold the tube or conch shell to one ear. The familiar "ocean" sounds are heard in shells. The sounds are those ambient sounds whose frequencies correspond to the resonant frequencies of the pipe or shell.

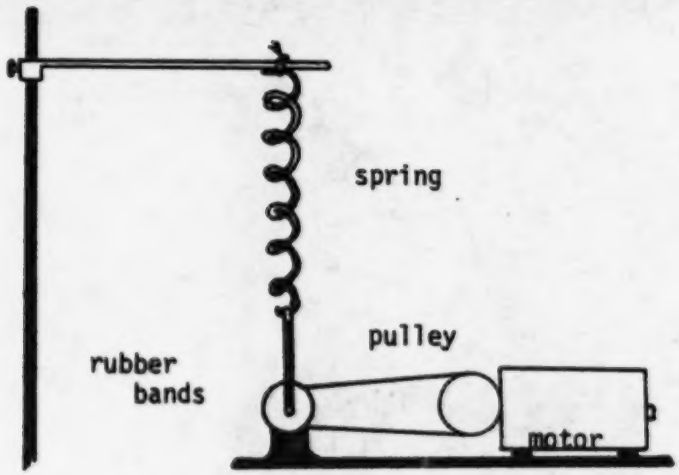
B. Procedure: Put one hand over the end of the tube and repeat.



38. RESONANCE OF A SPRING (II)

Materials: One electric motor (adjustable speed), an offset pulley, rubber bands, one spring, stand and clamps.

Procedure: Suspend a spring as shown and connect the spring to an offset pulley or a cam. The pulley should be attached to an adjustable-speed motor. By varying the speed of the motor, you can observe the natural resonant frequencies of the spring.



39. FILM LOOP: RESONANCE (II)

Tacoma Narrows Bridge (Holt, Rinehard and Winston, Inc.)
In 1940, the Tacoma Narrows Bridge in the state of Washington was destroyed by a wind-generated resonance. The wind produced a fluctuating force in resonance with the natural frequency of the bridge.

This is probably the most widely-used film loop ever produced and is perhaps the single best illustration of resonance.

39A. FORCED VIBRATIONS (I)

Materials: Tuning Fork.

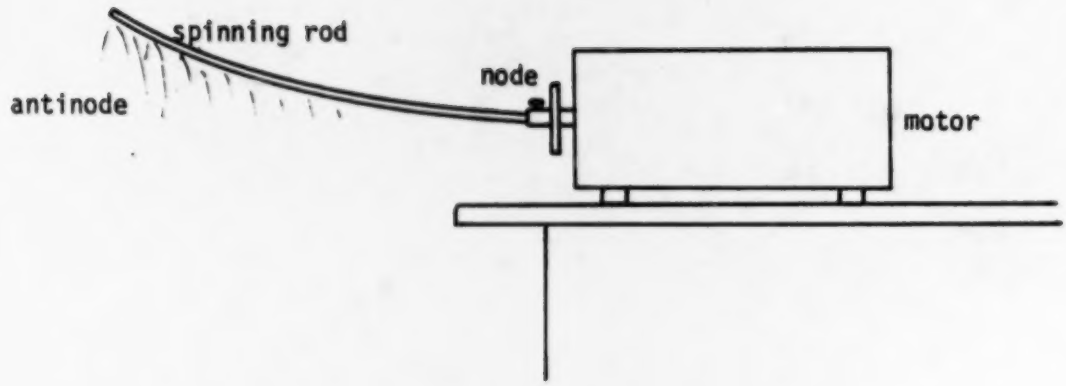
Procedure: Strike the tuning fork and listen for the change in pitch and loudness when the base is put in contact with a table. The surface of the table is forced to vibrate at a frequency other than its natural frequency. This is called a "forced vibration."

39B. RESONANCE OF A SPINNING ROD (II)

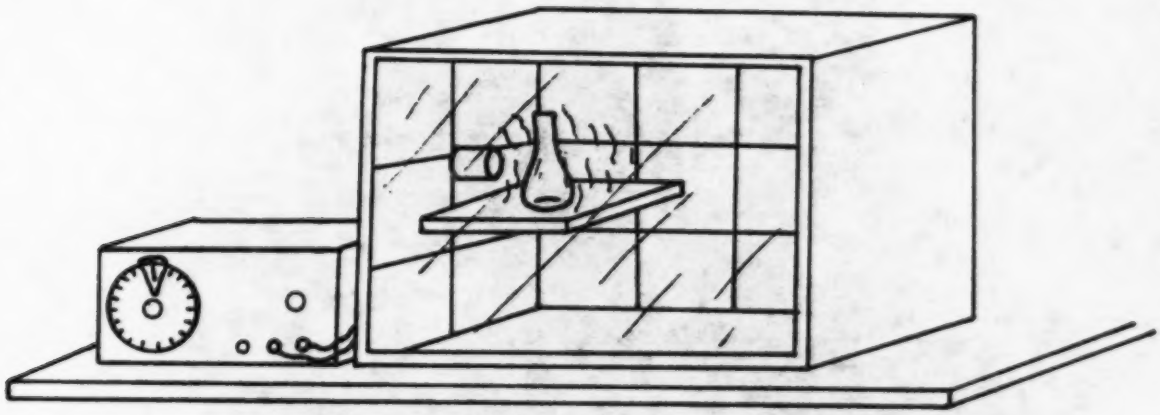
Materials: An electric motor (adjustable speed), a limber spinning or casting rod with the handle removed.

Procedure: Clamp the large end of the rod into the motor so that it can be rotated. Begin rotating the rod very slowly. Increase the motor speed so that the rotation becomes faster. As the resonant frequency is approached, the amplitude of the vibrations becomes larger. A node exists at the end of the rod that is clamped at the motor, and an antinode appears at the other end.

As the speed is increased further, the second mode of vibration suddenly appears. This is characterized by an additional node near the end of the rod.



40. SHATTER A WINE GLASS BY RESONANCE (II)



Materials: A homemade box with celatex tile walls, clear plastic sheet front, a 30-watt speaker, an audio oscillator, amplifier, and wine glasses. Actually, 250 and 400-ml laboratory beakers work better than wine glasses. The speaker is mounted on the outside of the box. Its output is delivered through a metal tube through the wall of the box at a height equal to that of the top of a beaker or wine glass.

Procedure: Connect the oscillator to the input of the amplifier; the output goes to the speaker. With the amplifier on maximum gain, vary the frequency until resonance is reached (as indicated by a small piece of paper folded over the rim of the beaker - it will jiggle when the beaker begins to vibrate.) A few seconds will be required for the vibrations to build up enough to break the beaker.

41. AIR TUBE TOY (I)

Purpose: To show the relationship of velocity to frequency.

Materials: Air tube toy and compressed air source such as vacuum cleaner in reverse or an air source for an air track. A hair dryer should do fine. (The toy is a plastic tube hose found in department stores toy departments.

Procedure: Swing the toy in a circle. Notice the frequency of the sound. Increase the speed of rotation. Higher harmonics are excited as the velocity increases.

To produce many higher modes of vibration (or harmonics), attach the tube to an air blower, such as that used to operate an air track. Or use a hair dryer, or vacuum cleaner operating in reverse.

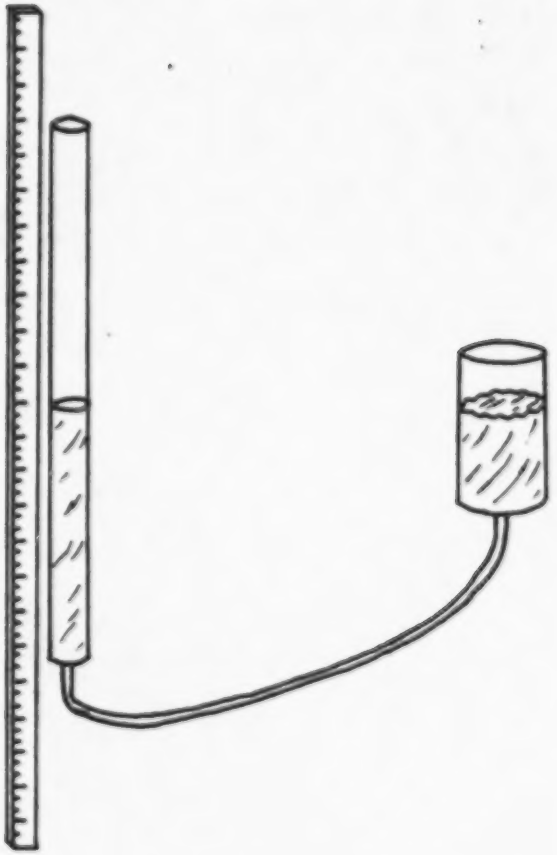
42. AIR COLUMN RESONANCE (I)

Purpose: To show resonance and the relationship of length to frequency and wavelength.

Materials: A glass tube attached to a water container, a ruler, a tuning fork, and Resonance Apparatus (Cenco 80-81) No. 84930-000, $99.00. This can easily be constructed from plastic pipe and tubing.

Procedure: Produce resonance in the air column by striking the tuning fork and holding it right over the top of the air column.

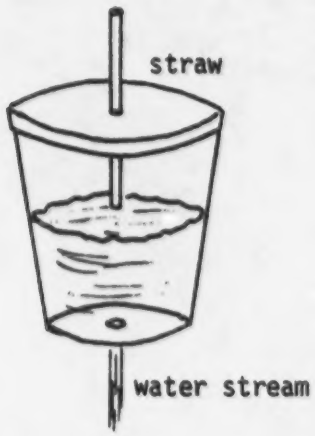
Change the length of the column by increasing or decreasing the water in the column. The position for which the sounds are are loudest correspond to modes of vibration of the closed air column.



42A. AIR-COLUMN RESONANCE IN A PAPER CUP (I)

Material: A paper cup with a plastic cap, a plastic straw.

Procedure: Fill the cup approximately three-fourths full of water. Insert the straw through an "x" cut in the plastic top. Notice the pitch of the sound produced when the straw slides up and down. Puncture the bottom of the cup with a pencil so that the water will drain out slowly. Observe the decrease in pitch as the straw continues to move up and down through the plastic cap.

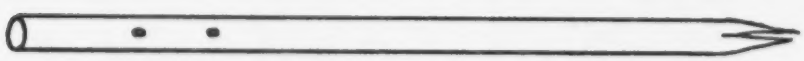


42B. STANDING WAVE IN A STRAW

Purpose: To demonstrate standing waves of various lengths in a straw.

Materials: A drinking straw and a pair of scissors.

Procedure: Chew one end of an ordinary drinking straw until it is almost flat. Use scissors to slightly taper this end. This approximates the shape of an oboe reed. Blow hard on the tapered end to produce a reed tone. One can then produce tone holes by cutting one or two holes in the straw. Note how the pitch changes as the holes are covered and uncovered. Finally, while blowing on the straw, use the scissors and cut lengths of about an inch off the straw and notice the change in pitch each time the straw is cut.



42C. WAVESHAPES (II)

Materials: Microphone, oscilloscope.

Procedure: Connect the microphone to the vertical input of an oscilloscope. Sing, talk, and play various musical instruments. Observe the waveshape on the oscilloscope. Waveshapes of musical sounds may be simple or they may be complex, but they all are regular with definite frequencies.

Slam a door or clap your hands loudly and notice the absence of a definite waveshape or frequency. This is a noise.

42D. OPEN AND CLOSED PIPES (I)

Materials: Toy whistle or small organ pipe, open on both ends.

Procedure: Blow through the whistle and notice the pitch. Press your hand against the open end to produce a closed pipe; blow again. The pitch should drop by one octave, as the fundamental frequency of a closed pipe is half that of an open pipe of the same length.

42E. OVERBLOWING TO PRODUCE HIGHER MODES OF VIBRATION (I)

Materials: Toy whistle or organ pipe.

Procedure: Blow gently throught the whistle and notice the pitch. Then blow very hard and notice that the pitch is much higher this time. One of the higher modes of vibration has been excited. Musicians refer to this as "overblowing" to reach higher "registers."

43. AIR COLUMN RESONANCE (II)

Materials: Audio generator, speaker, plastic cup, speakers.

Procedure: Attach the speaker to the oscillator and to the mount above the cup. Move a plastic cup back and forth below the speaker. By changing the length of the air column, one perceives standing waves.

44. RESONANCE OF OPEN AND CLOSED ORGAN PIPES. (I)

Materials: Organ pipes of different lengths.

Procedure: Blow through organ or music pipes of different lengths and observe the frequencies produced by the different lengths. Using one pipe, compare the frequencies produced by blowing gently through the pipe open and then by blowing through the same pipe closed. By blowing harder into the pipe (or "over-blowing") you can produce higher harmonics.

45. PRESSURE VARIATIONS IN A COLUMN OF GAS (II)

Materials: One long hollow aluminum pipe (five or six feet) with gas holes on top, a gas hose to fit onto one end of the pipe, one small speaker mounted in the other end of pipe and one audio generator.

Procedure: With a small speaker mounted in one end of the pipe (connected to an audio generator) and the other end of the pipe connected to a gas source, turn on the gas and light the gas which comes out of the small holes on top. Turn on the speaker and vary the frequency until a wave pattern is produced by the flames. This shows the variations in pressure in the tube caused by standing waves of sound inside the tube. Vary the frequency and see how many modes can be observed.

46. TRANSVERSE AND LONGITUDINAL WAVES ON A STRING (I)

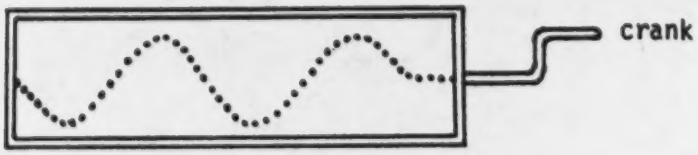
Materials: One long spring.

A. Procedure: With the spring taut, jerk one end up and then down rapidly, so as to send a single pulse down the spring.

B. Procedure: With the spring taut, compress a small section and quickly release it. Point out compressions and rarefactions. Also, notice reflection of waves.

47. TRANSVERSE WAVES - THE WAVE BOX (II)

Materials: A wave box, available from several equipment companies.



Procedure: Turn the crank to produce transverse waves. Increase the crank speed enough to see an increase in wave speed. Point out the crests and troughs.

48. CONSTRUCTIVE AND DESTRUCTIVE INTERFERENCE (II)

Materials: Audio oscillator, two inexpensive speakers, two stands, high-gain amplifier (optional), microphone (optional), oscilloscope (optional).

Procedure: Mount two identical speakers approximately one meter apart on a horizontal rod supported by a stand. Feed a 400-Hz signal into both speakers. As the stand is slowly rotated, the position of each person in the audience sometimes is at a point of constructive and destructive interference. (Listeners should cover one ear.) Reflections obscure the effect, but it is still noticeable. A mike fed through an amplifier to an oscilloscope and mounted on a second stand will display the effect visually.

49. FILM LOOP: INTERFERENCE (II)

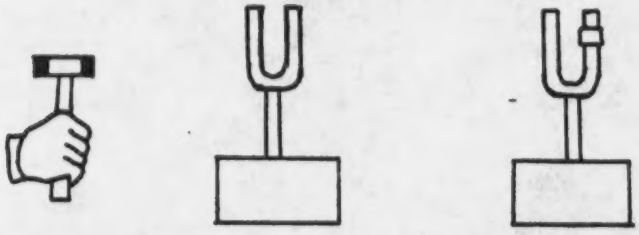
Interference of Waves, Ealing Film Loops, Cambridge, Mass. 02140, No. 80-2421. An interference pattern is produced by two sources vibrating in phase. At one point the motion is frozen, and superimposed marks identify the source separation and the wavelength of the periodic waves. The source separation is then doubled without changing the wavelength. Then keeping the separation the same, the wavelength is doubled. In the last sequence the interference pattern is slowly changed by continuously decreasing the wavelength.

50. FILM LOOP: DIFFRACTION (II)

Single Slit Diffraction 80-2405
With the slit width held constant, the wavelength is decreased and then increased. With the wavelength constant, the slit width is increased.

51. BEATS (II)

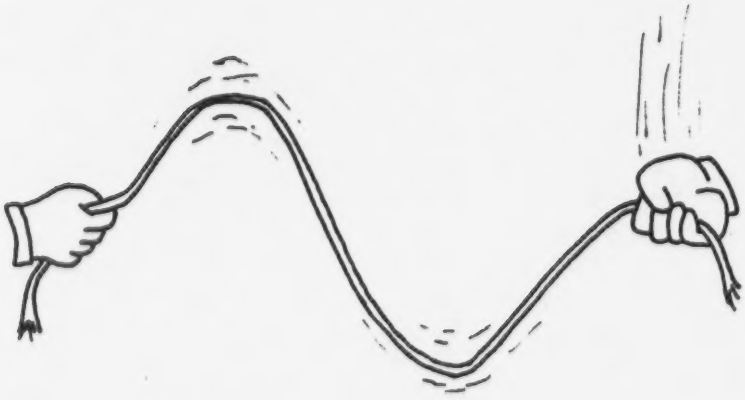
Materials: Two mounted tuning forks of the same frequency, a slide bar (or tape) to change frequency, hammer. Triple Plated Differential Duratone Forks (Cenco 80-81) No. 84585-000 for $115.00. (Less expensive forks would suffice.)



Procedure: Strike the forks. They sound the same. Attach a small clamp or piece of tape to one fork and strike again. Because the fork frequencies are now slightly different, one hears beats ($f_B = f_2 - f_1$). One can observe this visually by picking the sound up with a microphone and sending it to an oscilloscope.

52. STANDING TRANSVERSE WAVES ON A SPRING OR ROPE (I)

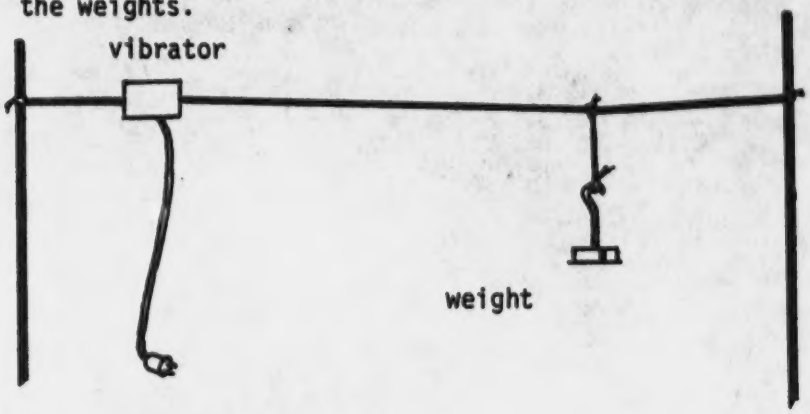
Procedure: While one person holds stationary one end of a long spring or rope, a second person sets up standing transverse waves by shaking the other end up and down. Varying the frequency correctly (this takes a little practice) produces several different modes.



53. STANDING WAVES ON A STRING (II)

Materials: Stands, string, weights and holder, vibrating instrument (Cenco '81 85102-000 for $55.00).

Procedure: Set up the apparatus as shown. Observe the wave produced. Locate the nodes and antinodes. Change the mode by increasing the weights.



54. PRODUCTION OF TWO DIFFERENT WAVES (I)

Purpose: To show how to produce transverse and longitudinal waves in a metal pipe.

Materials: A long metal tube or organ pipe and hammer, drying spray.

A. Procedure: Strike the tube held vertically with the hammer. Transverse waves are produced.

B. Procedure: Dry the tube and your hand. Use the spray (or resin) on the tube. (The spray is a deliquescent substance.) Quickly stroke the tube parallel to its length. A longitudinal vibration is produced.

55. LAWS OF VIBRATING STRINGS - THE GUITAR (I)

Materials: A guitar.

Procedure: Pluck a string on the guitar and note the frequency. Change the length of the string by moving the thumb to different frets. Change the tension by tightening the keys. This increases the frequency. The strings with smaller diameters produce higher frequenices. Illustrate this with two strings of different diameters.

55A. HARMONICS ON A VIBRATING STRING (I)

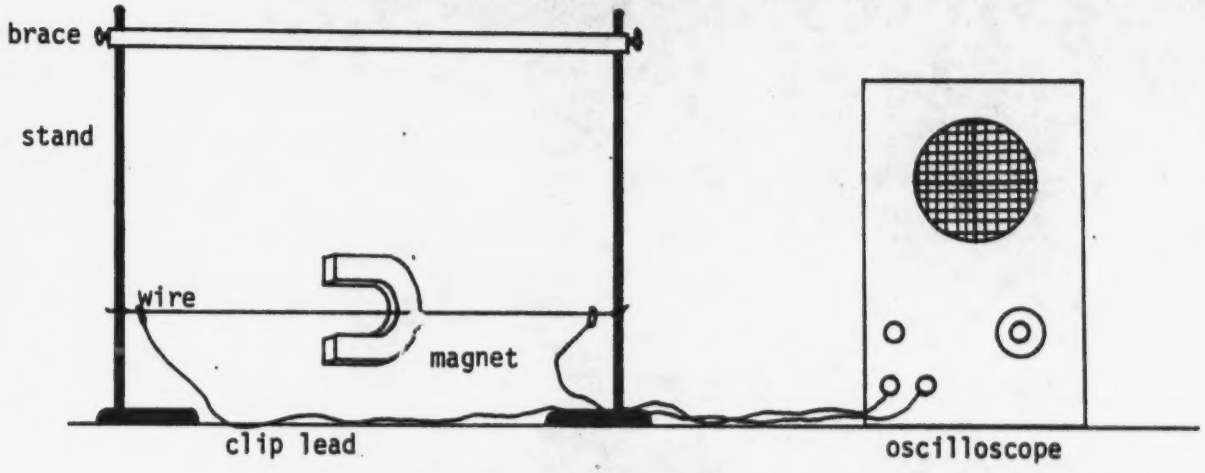
Materials: A guitar.

Procedure: Pluck a string on the guitar and notice the pitch. Then pluck the same string while gently touching the midpoint of the string and note the pitch again. (Do not press the string down onto the fingerboard.) The fundamental has been suppressed by putting a node at the center of the string. Now pluck the same string while gently touching it a point at one-fourth the length from either end and note the pitch produced.

55B. WAVESHAPES OF VIBRATING STRINGS (II)

Materials: Steel wire, strong horseshoe magnet, oscilloscope, clip leads.

Procedure: Stretch the wire very tightly between two supports. The wire should pass between the poles of the magnet. Use clip leads to connect each end of the wire to the vertical input of an oscilloscope. Set the vertical gain at maximum.

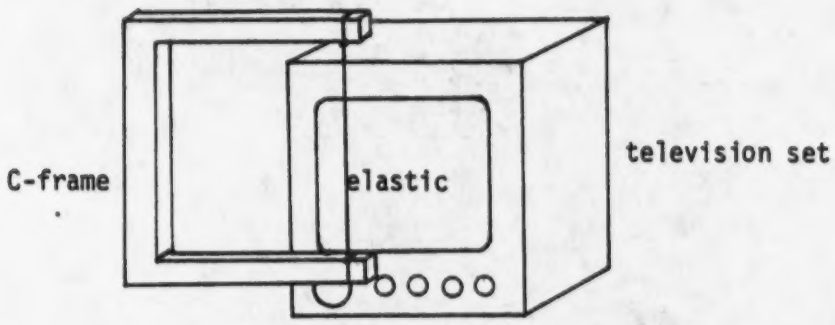


When the wire is plucked, the motion in the presence of the magnetic field produces an emf between the two ends of the wire. The shape of the electrical signal is identical to the shape of the vibrating string.

The waveshape obtained by plucking the string gently near the center is nearly sinusoidal, whereas plucking vigorously near one end produces a shape that departs noticeably from a sine wave. The more complex shape is due to the greater intensity of higher harmonics. This is also evident in the quality of the sound, as the presence of many harmonics corresponds to a "brilliant" or "bright" sound, whereas the absence of high harmonics results in a more "mellow" sound.

55C. SHAPES OF VIBRATING STRINGS (I)

Materials: A television set, four feet of 3/8-inch elastic cord, a C-shaped frame made of wood, and a violin bow (optional).



Procedure: Stretch the elastic tightly across the frame. Silhouette the string vertically against the lighted t.v. screen. When the string is plucked, one sees a wave on the portion of the string that is in front of the screen. Generally, the wave will be moving up or down. Adjust the tension in the elastic string until the wave has zero speed.

The waveshape of the string can now be clearly seen against the t.v. screen. The waveshape depends on the number and intensity of harmonics present, which, in turn, depends on how and where the string is plucked. Bowing the string produces a more complex shape than plucking. Thus the rich tone of a violin is due to the presence of many harmonics.

55D. TONE QUALITY OF PLUCKED STRINGS (I)

Materials: A guitar.

Procedure: Gently pluck a guitar string near its center. Use the fleshy portion of the finger or thumb. The quality or timbre is mellow as the fundamental dominates, and relatively few high harmonics are produced with appreciable intensity.

Now pluck the string at the same place, but use the fingernail or any hard, sharp object. More harmonics will be excited, and the sound will be brighter.

Use the fingernail to pluck the string briskly near one end. The tone is now much brighter due to the presence of many harmonics of relatively high intensity.

Guitarists control in this manner the tone quality produced.

56. EFFECT OF WRAPPING STRINGS ON MUSICAL INSTRUMENTS (I)

Materials: One wrapped guitar string

Procedure: Partially unwrap a guitar string showing structure. Call the students' attention to the lightness of the string under the wound wire. Attach the string to a guitar and play a note. Play a normal string on the guitar for comparison. (Strings are wrapped to increase mass while retaining flexibility.)

57. THE AUDIBLE FREQUENCY RANGE (II)

Materials: An audio generator with speaker and an oscilloscope (optional).

Procedure: Demonstrate the frequency range to which the human ear is sensitive by varying the frequency from about 15 Hz to 20000 Hz. If an oscilloscope is available, observe the change in wavelength as the frequency is increased or decreased.

58. SOUND AS PRESSURE VARIATIONS (II)

Materials: Perforated saw blade disk. Rows of holes form concentric circles around the center of the disk. The holes on the inner ring are irregularly placed. The blade is attached to the rotating shaft of a motor. Also, one needs compressed air, a rubber tube and a dropper type glass nozzle.

Procedure: Direct the air jet on the holes of the rotating disk. When the air is directed on the irregularly shaped ring, no definite frequency is produced. This is a noise. Direct the air to the rings of regularly spaced holes. Different frequencies are produced by the various circles of holes.

59. PROPAGATION OF SOUND (II)

Materials: A bell jar with a base pump plate, a bell or buzzer connected to a 6-V source, and a vacuum pump.

Procedure: To demonstrate that sound requires a medium for transmission, suspend a bell or buzzer in a bell jar or vacuum jar. Connect the vacuum pump to the jar and pump the air out of the jar while the bell is ringing. Notice how the sound of the bell fades out. After the air is pumped out, turn the pump off and slowly allow air to reenter the jar. The sound will become progressively louder.

60. DOPPLER EFFECT (II)

Materials: A small tone generator and string.

Procedure: Tie the tone generator to about three feet of string. Turn it on so that it generates a steady frequency and whirl it rapidly in a circular motion toward the class to demonstrate the Doppler effect. As the generator approaches the class, students will hear a higher frequency. They will hear a lower frequency as it travels away from them. Or, instead of an audio generator, use a small whistle that sounds when whirled on a string.

61. DOPPLER EFFECT (I)

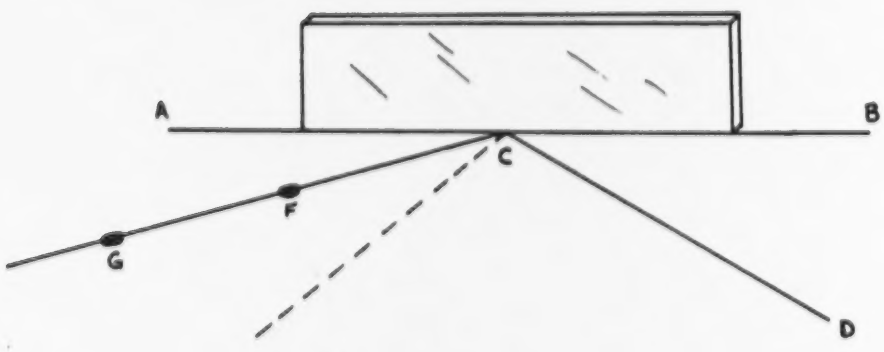
Material: Tape recorder and tapes.

Procedure: Tape the sound of an approaching car horn or train until it has gone past. Sounds of a police siren can also be used.

62. SIMPLE REFLECTION (I)

Materials: A plane microscope slide. The slide will be used as a mirror, straight edge, and protractor.

Procedure: The law of reflection can be deduced by following these steps. Lay the slide on a sheet of paper and draw line AB. Lay the slide across AB and draw a second line CD that intersects AB at any angle. Hold the slide on line AB so that the plane of the slide is perpendicular to the sheet of paper. Look into the slide from a point G and you will see the image of CD clearly. Along the image of CD, place two dots F and G and connect these dots in a line to AB. Use the slide as a protractor and draw a dotted line perpendicular to AB and crossing through the point of CD and FG. Now, by folding the paper along the dotted line CD and FG will be found one on top of the other, thus proving the angle of incidence equals the angle of reflection.



62A. PROPERTIES OF REFLECTIONS IN PLANE MIRRORS (I)

Purpose: To show that a person can see his/her full length in a mirror if the mirror is twice the height of the person and that this does not depend on the distance of the person from the mirror.

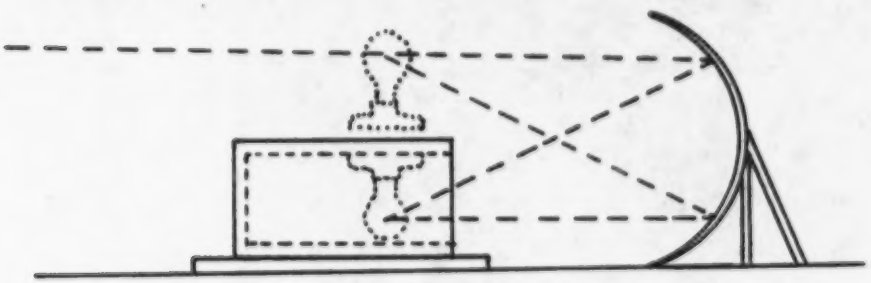
Materials: A mirror and a meter stick.

Procedure: Measure the length of the mirror with the meter stick. Place the meter stick in front of the mirror with top of the stick at eye level. You will see a length of the meter stick that is twice the length of the mirror. Move the meter stick different distances from the mirror to convince yourself that changing the distance will not change the fraction of the total length that can be seen.

63. REAL IMAGE (II)

Procedure: Construct a wooden box with a light fixture and bulb inside the box. Leave the box open on one end. Place another light fixture directly above the one in the box. If you place a concave mirror at the center of curvature, a reflection of the light bulb will appear in the empty light socket as you view it from the front of of the box. The image will be real, inverted, and the same size as the object.

This will amaze students. As they move closer to the side the bulb will disappear. Ask students what happened to the image. (This would be an excellent demonstration to stir up curiosity just before you start studying reflection.)



64. DETERMINING THE FOCAL LENGTH OF A CONCAVE MIRROR (I)

Procedure: Hold a concave mirror near so that you can see your upright image clearly. Move backwards until no image appears in the mirror. Your distance from the mirror now will be the focal length.

65. IMAGE FORMED BY A CONVEX MIRROR (I)

Procedure: Notice what a convex mirror does to your image as you change your distance from the mirror. As you move farther away, the image will become smaller. The image produced in a convex mirror is virtual, erect, and smaller than the object.

66. CONCAVE MIRROR USED TO REFLECT IMAGES ON A WALL (I)

Procedure: Darken the room and leave part of one window open so that objects from the outside can be reflected on a white wall inside the room. This cannot be done with plane or convex mirrors because they do not project real images.

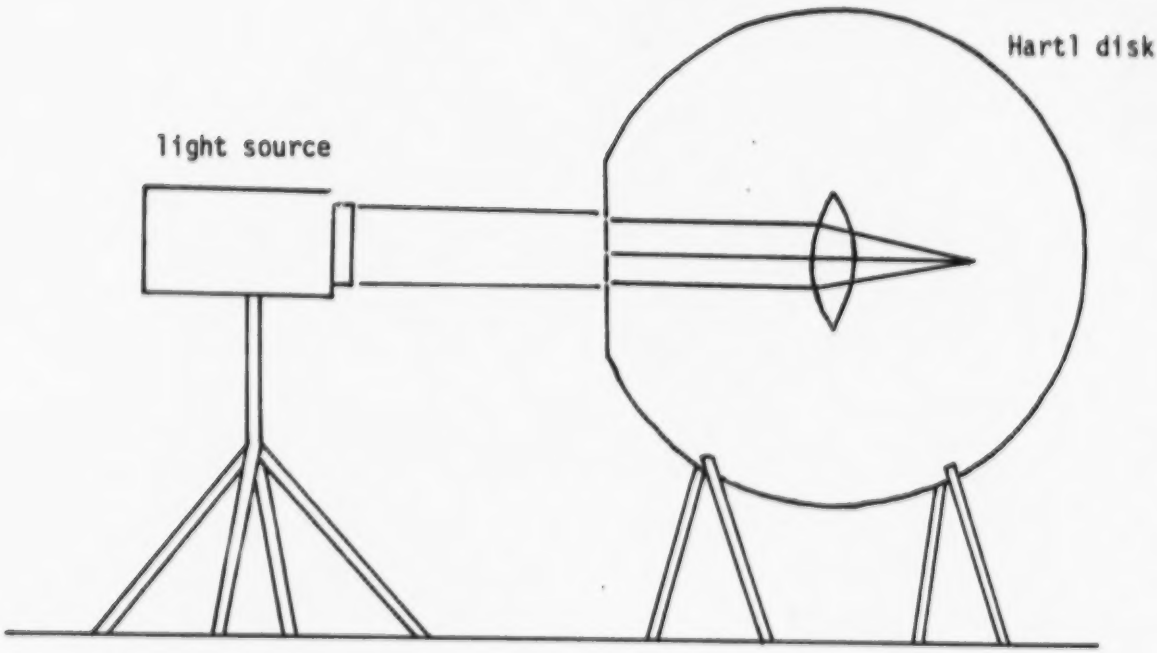
67. CONCAVE MIRROR AND PLANE MIRROR USED TO REFLECT IMAGES ON A WALL (I)

Procedure: A plane mirror placed between a concave mirror and its image will deflect the image, as in a Newtonian-focusing telescope.

68. REFRACTION AND REFLECTION (II)

Materials: For this demonstration one will need an optical (Hartl) disc and a set of concave and convex lens and mirrors. These can be ordered as a kit from Science Kit # 42500 for $138.43. One will also need a strong light source which sends parallel rays. This could be a Helium-Neon Laser from Science Kit # 42468 for $99.50.

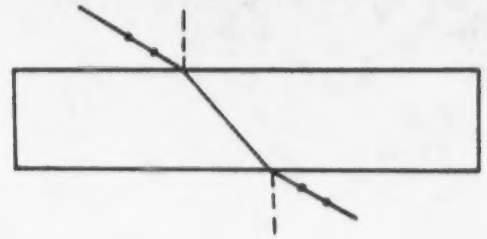
Procedure: Set up the Hartl Disc so that the light shines through the slits. Place the various lens in the lens holder and draw a diagram of the way light is refracted or reflected. Also notice if there is any internal reflection.



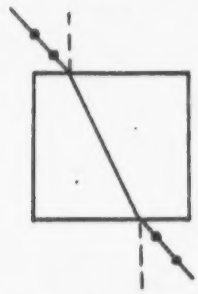
69. REFRACTION (I)

Materials: It is convenient to use square and triangular glass blocks. These can be bought through Science Kit # 62750 & # 62745 for about $5.00 each.

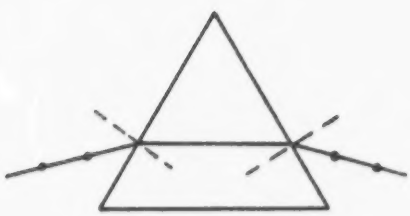
A. Procedure: Take the square piece of glass and draw a line along one edge. Then draw another line to represent a ray incident to the plane. Take two stick pins and stick them at any two points along the ray. Stand the glass edgeways along the plane and with two more pins, place them in line with the other pins as you see them through the glass. Connect the pin points to represent the refracted ray. Draw the normals for each ray.

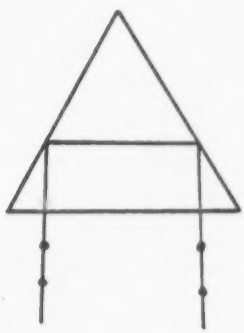


B. Procedure: Repeat the procedure above, but lay the glass square down flat.



C. Procedure: Repeat again using the triangle. Notice total internal reflection when it occurs.





70. FOCAL LENGTHS OF LENSES (I)

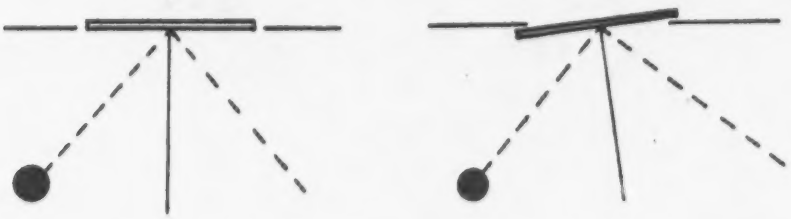
Materials: Use an assortment of lenses: a thin double convex lens, a thick convex lens, and a double concave lens.

Procedure: Focus an image from outside a window through the lens onto a sheet of paper. Notice the different focal lengths of convex lenses.

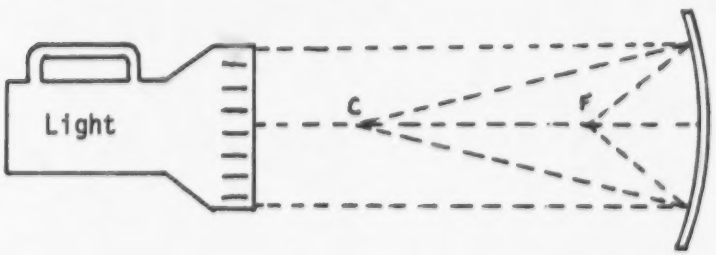
71. BLACKBOARD OPTICS (II)

Materials: Klinger Educational Produces Corp. 83-84 Parsons Blvd., Jamaica, NY 11432. 1C04100, Blackboard Optics Kit (Suction) $228.00. Some of these can be done with an inexpensive light source, mirrors, and glass blocks.

A. Procedure: The Law of Reflection. An incident ray is projected obliquely to the mirror surface. The mirror line and normal are added to show the angle of incidence equals the angle of reflection. The mirror is rotated to a second position.



B. Procedure: Focal Length of a Concave Mirror. The center of curvature is located by means of a ray which reflects back on itself. Rays parallel to the principal axis reflect through principal focus which is located midway between C and the vertex of the mirror on the principal axis.



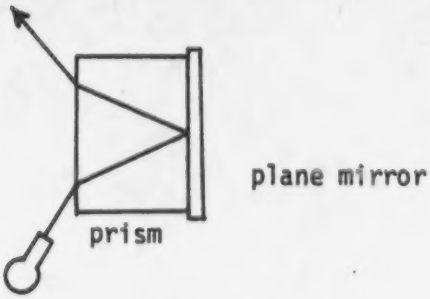
C. Procedure: Focal Length of a Convex Mirror. The center of curvature is found by a ray which reflects back on itself; this ray is extended behind the mirror until it intersects the axis.

BLACKBOARD OPTICS (continued)

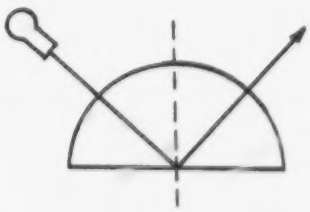
D. Procedure: Real Image formed by Concave Mirror. Pencils of light from two projectors are made to intersect at the object point.

E. Procedure: Simple Refraction Lens Dense to More Dense. The lower edge of the parallel-sided prism is made opaque by taping a sheet of paper to it. The phenomenon of refraction is then clearly visible when a pencil of light is projected obliquely at the upper face. The chalked normal extension of the refracted ray enables the teacher to label the angle of incidence and angle of refraction.

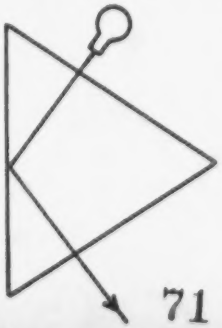
F. Procedure: Simple Refraction - More Dense to Less Dense Medium. The opaque paper is replaced by a plane mirror. This produces a return pencil of light which demonstrates the deviation away from the normal as the ray passes from the more dense to the less dense medium.



G. Procedure: Semi-Circular Body - Critical Angle. The projector is placed so that the pencil of light lies along an extension of a radius of the disc. The semi-circular body is then rotated until total internal reflection occurs. By chalking in the appropriate normal, the critical angle for this material is readily measured.

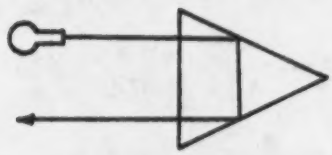


H. Procedure: Triangular Prism - Total Internal Reflection 90° Deviation. A single internal reflection in the large triangular prism is obtained in the manner shown. The 90° deviation thus produced is used in the design of some types of modern periscopes.



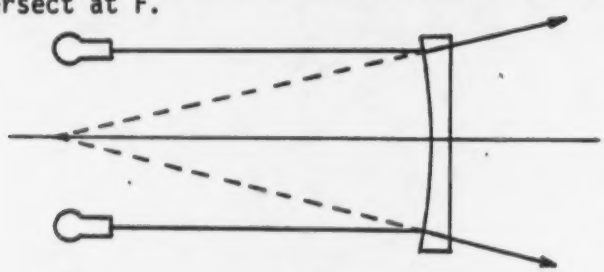
BLACKBOARD OPTICS (continued)

I. Procedure: Total Internal Reflection 180° Deviation.
Reorientation of the prism results in a total deviation of 180° achieved by two internal reflections. The basic principle of prism binoculars is thus demonstrated. These demonstrations also show that the critical angle for plexiglass is smaller than 45°.

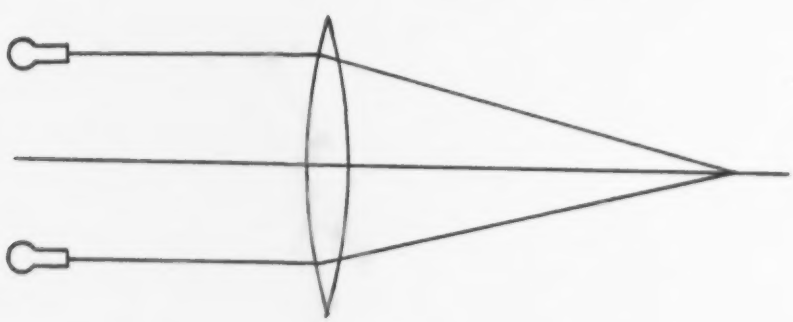


J. Procedure: Focal Length of a Plano-Convex Lens.
The focal length of the plano-convex lens is determined by means of a pair of pencils of light parallel to the principal axis.

K. Procedure: Focal Length of a Plano-Concave Lens.
Parallel pencils of light are employed to locate the principal focus of the concave lens. In this case, virtual rays are chalked in as extensions of the refracted rays behind the lens. They intersect at F.

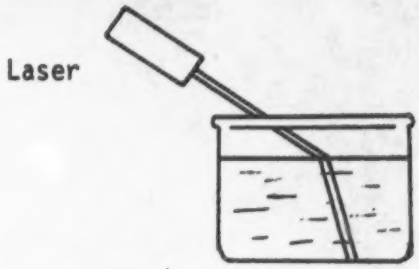


L. Procedure: Focal Length of a Double Convex Lens.
Two plano-convex lenses, which are supported in contact by a clamping bar, form a double convex lens. The relationship between total lens curvature and focal length is easily noted when this is compared with J above.



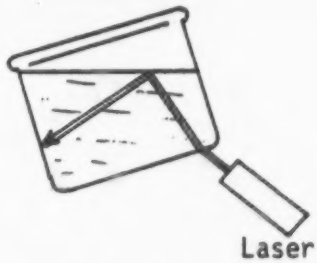
72. DEMONSTRATIONS ON REFLECTION, DIFFRACTION, INTERFERENCE AND REFRACTION (II)

A. Procedure: Refraction and Internal Reflections (Science Kit, Student Laser, $290.00). Fill a beaker with water and add a small amount of baking soda then stir to make the water cloudy. With the lights out, aim the laser beam into the top surface of the water. Tap two chalk erasers together in the beam. (The chalk dust will make the beam visible.) Observe the refraction of the beam as it is bent toward the normal where it enters the water.



Internal reflection will be observed at the glass-to-air interfaces for appropriate angles of incidence.

B. Procedure: The Critical Angle. Use the same beaker as in A. Shine the beam through the side of the beaker through the water so that it strikes the water-to-air boundary. Increase the angle of incidence of the beam to the water-to-air boundary until the critical angle is surpassed and total reflection is observed. (To reach this angle the beaker may have to be tilted.)

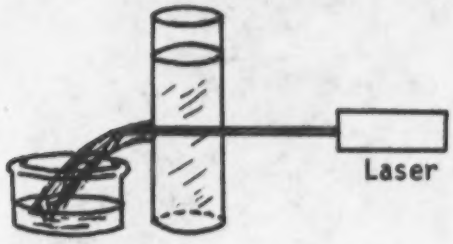


Also aim the laser up through the bottom of the beaker. One will see light on the ceiling until the critical angle is reached. Then light will be totally reflected from the upper water-to-air interface, causing the light to strike the floor.

DEMONSTRATIONS ON REFLECTION, DIFFRACTION, INTERFERENCE AND POLARIZATION (continued)

C. Materials: A cylinder with a plugged hole in its side.

Procedure: Total Internal Reflection in a Water Stream. Fill the cylinder with water. Aim a laser through the cylinder at the plug. When you remove the plug, the laser light will follow the path of the water flowing out of the hole. Very little light will emerge through the side of the stream. As the water runs into a beaker, you can see the internal reflection of the laser light.



D. Procedure: Refraction in Glass. One needs two square prisms and a laser light source. Put the two prisms together and put them into a laser beam light. As one changes the angle of the prisms to the light, students can see the point jump on a projection screen. There will also be some internal reflection which will beam back to the wall behind the prisms.

E. Procedure: Shine the laser beam through several different diffraction gratings and project the beam onto a white wall or screen. Observe the pattern of light and dark spots caused by interference of the diffracted light waves. Shine the beam through two or more slits, using various distances between the slits. (Lantern slides with etched slits are available commercially.)

73. INTERFERENCE (I)

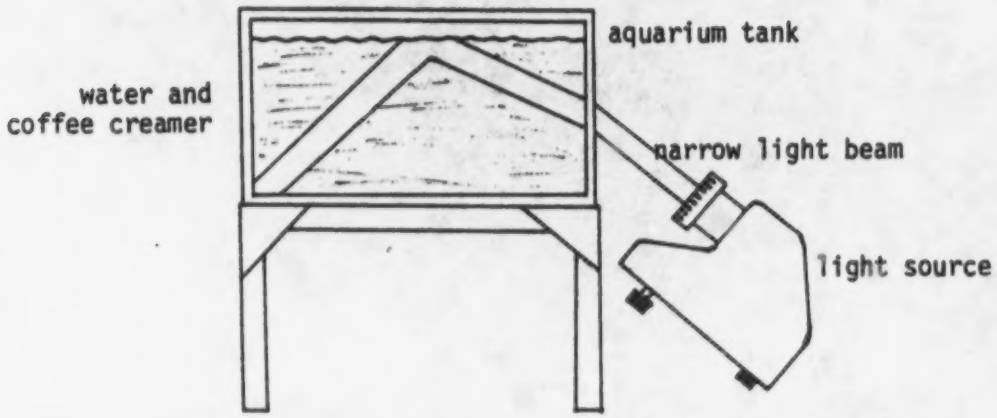
Procedure: Let students look at a light source through multiple slits. The students will see dark spots separating light ones. These dark spots are points of destructive interference.

74. INTERFERENCE PATTERNS THRU WIRE SCREEN OR CLOTH (I)

Procedure: As you look through a piece of wire screen or cloth at a light source, you can see the interference patterns. One can also shine the laser light through the screen wire and project the patterns on a viewing screen. For more complicated patterns, use two thicknesses.

74A. REFRACTION AND TOTAL INTERNAL REFLECTION (I)

Materials: If a laser is not available, parts A and B of No. 72 can be performed with a large beaker or, better, a small aquarium filled with a mixture of water and baking soda or coffee creamer, and a film strip projector.



Procedure: To demonstrate refraction, aim a beam of light from the projector from above the water surface. In addition, a plane mirror placed where the water strikes the bottom of the tank demonstrates the law of reflection.

Total internal reflection from the top water-to-air surface can be seen by introducing the light beam from the side, as shown. To emphasize the absence of a refracted beam in the air, hold a piece of paper above the tank parallel to the water surface.

75. INTERFERENCE FRINGES IN MONOCHROMATIC LIGHT (I)

Procedure: Using a sodium light, take two square glass plates and place them on top of each other under the light. The interference patterns from the light from the bottom of the top plate and the top surface of the bottom plate will be seen. The dark and light areas in the interference pattern are called fringes. If you touch the glass you change the pattern because the surfaces of the plates are brought closer together.

76. POLARIZATION OF LIGHT (I)

Procedure: Use a set of lenses from a pair of polaroid sunglasses. As light passes through one of the lenses, it is polarized in one plane. If you hold the second lens up in front of the first and rotate it 90°, you will block out all the light.

77. ABSORPTION OF LIGHT (I)

Procedure: As you look at one sheet of "transparent" cellophane, it seems to be perfectly transparent. However, some of the light is being reflected, some is absorbed, and some is transmitted. If you put twenty five or thirty sheets together, they appear opaque.

78. FIBER OPTICS AND TOTAL INTERNAL REFLECTION (II)

Materials: Fiber Optics Demonstrator (Sargent Welch 3544, Each $67.50. includes fibers in sheath, penlight powered by two 1.5-V size AAA batteries).

Procedure: A light beam may be bent into any shape by this device with almost no decrease in light intensity. Transmission occurs due to many total internal reflections in each fiber.

79. COLOR SUBTRACTION WITH SODIUM LIGHT (I)

Procedure: Get three notebooks of different colors. Get three objects whose colors are known, such as a coke can (red), a sprite can (green), and a Dr. Pepper can (blue). Place these cans under the sodium light. (Light of a different color could be used - merely wrap colored cellophane around a white light source.)

The room should be dark so that no white light can get in. The cans and notebooks will appear to be black under light because the objects will not reflect yellow light.

If you place a Mellow Yellow can (yellow) under the light it will appear yellow.

80. CHAIR-ARM DEMONSTRATION ON COLOR (I)

Materials: You will need a red and blue color crayon, a red and blue light filter, a piece of white paper and a piece of black paper.

Procedure: Take the white paper and make a red mark and a blue mark. Look through the red filter at the red mark and look through the blue filter at the blue mark. You will not be able to see the marks because the marks and the paper both reflect each color so that the whole area will appear as the same color because the filter transmits only its particular color.

Repeat the above, only with the black background. This time you will only see the mark because the black background is absorbing all the light and the mark is reflecting its color.

If you look at the color marks with the opposite color filters you will see the marks, but they will appear black because the mark reflects only its color, and a different color filter will absorb the color instead of transmitting it.

81. COLOR ADDITION WITH A COLOR BOX (II)

Materials: A color box can be purchased from Fisher Scientific #42207 for $354.32.

Procedure: The box contains red, blue and green light bulbs. By mixing the colored lights, you can produce the primary complements. (A Primary complement is produced when any two primary colors are added together.

82. COLOR-ADDITION SLIDE (I)

Procedure: Using a 35mm slide projector, show a color slide which has circles of red, green and blue overlapping each other. This shows the results of adding the primary colors.

83. PRODUCTION OF A RAINBOW (I)

Materials: Use a ring stand with a soft clamp to hold an equilateral prism (Science Kit #62735 - $7.00). Use the light source from earlier optic demonstrations.

Prodecure: Focus the light on the prism and adjust it until a rainbow is formed on the wall.

Using the slide projector, show a color slide of a real rainbow just above the one you produced and compare them.

84. COLOR SUBTRACTION (II)

Materials: An overhead projector (Science Kit #73749-01 for $253.00) and a set of filters (Science Kit #66516 for $2.15).

Procedure: Place one of the filters on the overhead, say green. Then only green light is being transmitted. If you place a red filter on top of it, the image will be black.

84A. VIEWING AN OBJECT THROUGH A PINHOLE (I) *

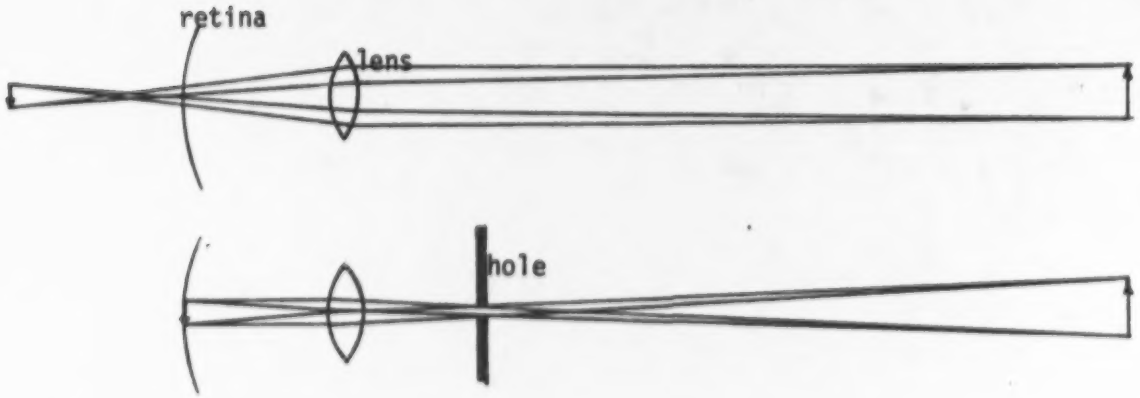
Purpose: To show that an object can be seen clearer and closer when the aperture through which it is viewed is small.

Materials: Pin, heavy paper or index card.

Procedure: Make a pinhole in the paper. Look through the paper at the pin (or another object). Bring the pin closer until it is in focus.

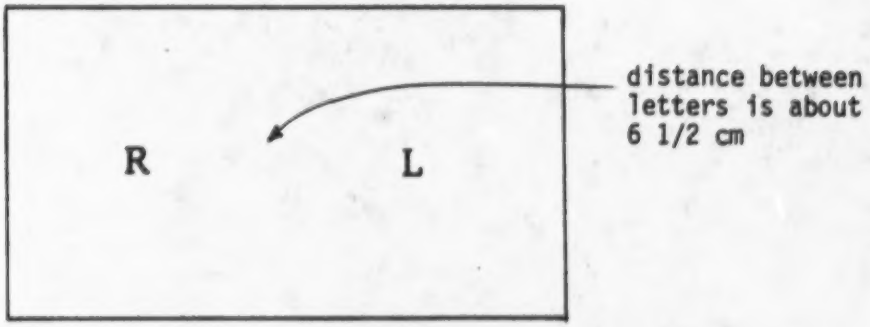
With no pinhole, the image of an object placed closer to the eye than the "near point" (approximately 25 cm) is not in focus. The small aperture of the pinhole eliminates many of the light rays therefore allowing those that are remaining to create a well-defined image at the retina.

*Stollberg and Hill, Physics Fundamentals and Frontiers, p 448, Houghton and Mifflin, Boston, 1980.



84B. THE BLIND SPOT IN THE HUMAN EYE (I)

Materials: One index card per student as prepared below.



Procedure: Hold the card at arm's length from your eyes. While looking at at the letter "R," close your left eye and slowly move the card closer to your face. Repeat using the left eye.

As the card is moved closer to the face, both letters are seen even though the eye is focused on only one. At some point as the card is advanced toward the face, the letter "L" suddenly disappears. The light rays have struck the "blind spot" on the retina; this is a location on the retina which contains no nerve endings.

85. POSITIVE AND NEGATIVE CHARGE (I)

Materials: A rod or strip made of rubber, amber or vinyl, a wool cloth or piece of fur, a glass rod or strip of acetate, a piece of silk or a small plastic bag, a graphite-covered pith ball hanging by a thread from a support.

Procedure: Rub the vinyl strip with the wool cloth. Bring the charged strip near the hanging graphite-covered pith ball. The ball will be attracted until it touches the strip. Then the ball becomes negatively charged by the negative strip and the ball is repelled. Rubbing a glass rod with silk or an acetate strip with a plastic bag will charge the rod positively. It will attract the ball that the vinyl strip repels, thus demonstrating two kinds of charge.

86. CHARGING BY INDUCTION (I)

Materials: Vinyl strip, wool cloth, graphite-covered pith ball with thread attached, a hollow metal sphere (the shape is not critical) mounted on an insulated stand.

Procedure: Charge the vinyl strip with the wool cloth. Charge the pith ball negatively by touching it with the strip. With your left hand on the metal sphere, bring the charged strip near the sphere, but do not touch it. Remove your hand. Negative charges will have escaped through your hand, leaving the metal positively charged. Demonstrate that this is so by bringing the negative pith ball near the metal.

87. CONDUCTORS AND INSULATORS (I)

Materials: A vinyl strip, a wool cloth, a graphite-covered pith ball (or an electroscope), strips of wood, glass and metal.

Procedure: Suspend the strips of wood, glass and metal by string. Touch one end of a strip to a neutral pith ball or an uncharged electroscope. Touch the other end with a negatively-charged vinyl strip. In the case of metal, the pith ball will become charged, just as in the case of direct contact with the vinyl strip (or the leaves of the electroscope will diverge). This demonstrates charge conduction.

The glass and wooden strips, if clean, will not conduct the charge. The strips must be suspended, as holding them with your hand will "short circuit" the charge.

88. CAPACITORS (I)

Materials: As many types of capacitors as possible. Possible sources are electric shops, television repair shops.

Procedure: Pass around the capacitors, explain their structure and what the various types are used for. Disassemble some capacitors so that the structure is evident.

89. CHARGING AND DISCHARGING CAPACITORS (I)

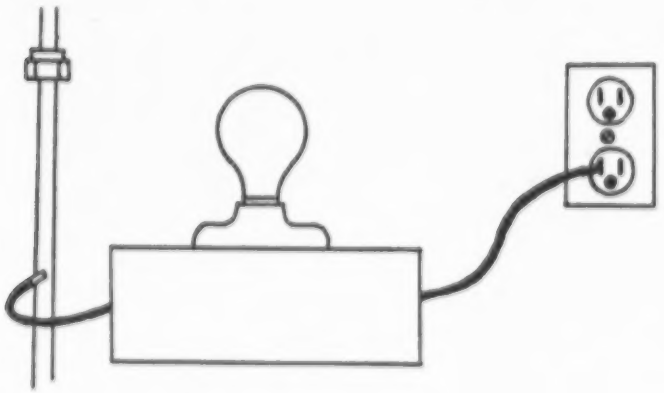
Materials: Two 6-volt batteries in series or a d.c. power supply, a large electrolytic capacitor (20,000. μF or so, if available), connecting leads.

Procedure: Charge the capacitor with the batteries or power supply (twelve to thirty volts). Disconnect the emf source and leads to the capacitor. With a single lead or screw driver, short the capacitor by touching both terminals. An impressive spark is seen for large capacitances.

90. THE GROUND AS A CONDUCTOR (I)

Materials: An a.c. extension cord, a light bulb mounted in a socket. The insulated wires attached to the socket should have exposed ends.

Procedure: First stick one wire from the bulb into each side of the a.c. extension cord (plugged into a wall receptacle). This lights the bulb. Remove the wire from the ground side, and the bulb goes out. Touch this wire to an unpainted water pipe (which leads to the ground). With the "hot" wire still connected, the bulb lights again. This demonstrates that the earth is a good conductor as the circuit is now being completed through the ground. (Be Careful!)



91. MAGNETIC EFFECTS FOR ELECTRIC CURRENT (I)

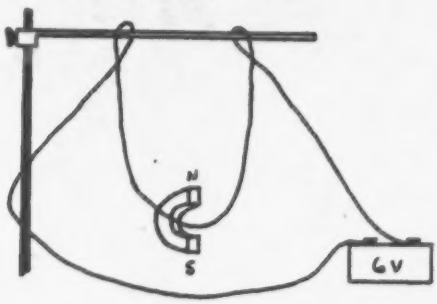
Materials: A compass, a bar magnet, lead wires, a low-voltage d.c. source (2.0 to 6.0 volts, batteries or power supply).

Procedure: Bring the bar magnet near the compass. Deflection of the compass demonstrates the behavior of a magnetic field. Complete an electric circuit using just the d.c. source and one or two connecting wires. Position the wire near the compass needle and observe the slight deflection. This demonstrates the existence of a magnetic field caused by the current.

92. THE MAGNETIC FIELD PRODUCED BY AN ELECTRIC CURRENT (I)

Materials: A strong horseshoe magnet (See Science Kit No. 62310 for $7.59 or Sargent Welch, No. 544380-80 for $156.00), connecting wires, ring stand, clamp and bar, a piece of stiff wire, and a 6-volt d.c. source. (Any strong horseshoe magnet will do.)

Procedure: Suspend the stiff wire freely from the clamped bar between the poles of the horseshoe magnet.



When the leads are connected to six volts, the magnet exerts a force on the stiff wire. Reversing the polarity reverses the direction of the force. Notice that the force is perpendicular to the direction of the current and to the direction of the magnetic field.

92A. FORCE BETWEEN TWO CURRENT-CARRYING WIRES (I)

Purpose: To demonstrate the forces present in wires which are conducting current.

Materials: A 12-volt dc source, such as an automobile battery, connecting wires, two stands, two clamps, a switch.

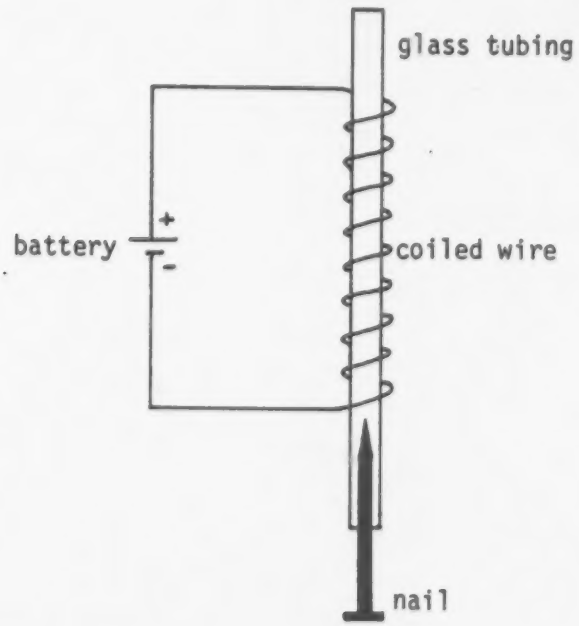
Procedure: Fold the wire once so that its doubled length is suspended loosely between the stands. The two lengths should be nearly parallel and separated by approximately one centimeter. When the switch is closed, the wires will attract or repel each other, depending on whether the currents are in the same direction or in opposite directions.

92B. A SIMPLE ELECTROMAGNET (I)

Purpose: To show that current in a loop of wire produces a magnetic field.

Materials: Glass tubing, no. 22 insulated wire (enough to make about 50 turns), 6-volt battery, nail.

Procedure: Coil the wire tightly near one end of the glass tube and connect it to the battery. When the circuit is completed, the nail will be lifted.

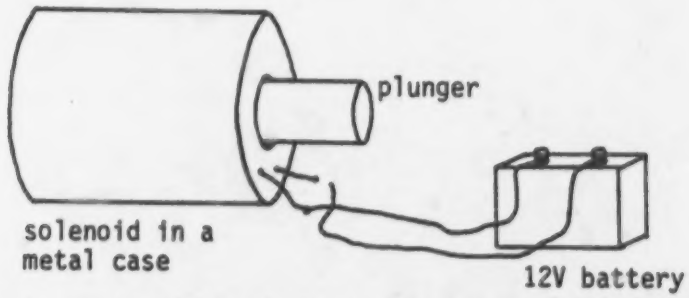


92C. AUTOMOBILE STARTER SOLENOID (II)

Purpose: To demonstrate the use of electromagnetism to make a switch.

Materials: A starting motor solenoid, a 12-volt dc source, as an automobile storage battery, connecting leads.

Procedure:



Connect one terminal of the battery to either terminal of the solenoid. Connect the other terminal momentarily and observe. When the circuit is completed, an electromagnetic force is created which attracts the magnetic material, produces contact, and completes a circuit. When the circuit is broken, a spring pushes the plunger out to break the circuit.

The solenoid is a useful electrical switch. It can be used to turn on and off various electrical or mechanical devices. For example, on a washing machine an electrical signal can be used to turn water on and off.

93. MAGNETIC FIELD OF A BEAM OF ELECTRONS (I)

Materials: A strong permanent magnet and an old oscilloscope or television set. (Do not use a good scope or t.v., as the magnet could permanently damage them.)

Procedure: Turn the oscilloscope on and focus the beam to a small spot. Bring the permanent magnet near and notice the deflection of the beam. This demonstrates that the beam is itself a magnet, as it is repelled and attracted by the permanent magnet.

94. MAGNETIC LINES OF FORCE (I)

Materials: A hand full of iron filings and a bar magnet. The filings can be obtained from shop teacher.

Procedure: Spread a layer of filings across a sheet of paper and lay the magnet in the center. The filings will be attracted in a pattern which will show the lines of force.

95. CONSTRUCTION OF ELECTROMAGNET (I)

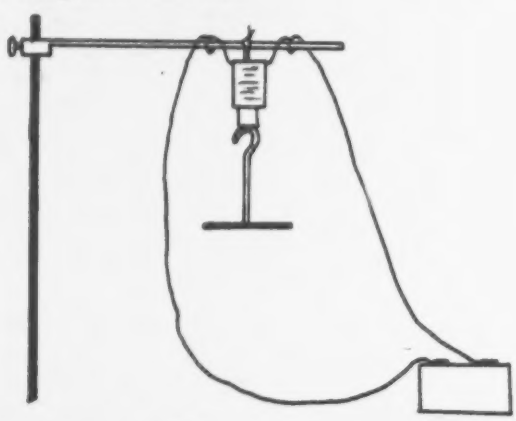
Materials: An iron bar, several yards of insulated wire and a d.c. power source.

Procedure: Wrap the wire around the iron bar several times, then put a current through the wire. The bar will then attract objects.

96. DEMONSTRATION OF THE STRENGTH OF AN ELECTROMAGNET (I)

Materials: An electromagnet (iron clad) (Cenco No. 79647-000 or Science Kit #61603-01 for $30.25), a 6-volt battery, ring stand and several heavy weights.

Procedure: When current is induced into the coil inside the iron case, eight to ten kilograms can be added onto the hanger. This shows how strong electromagnets can be.



97. MAGNETIZING A PIECE OF IRON (I)

Materials: A strong magnet and an iron bar.

Procedure: Stroke the iron bar several times to align the domains and the iron bar will become a magnet. If you strike it against something, it will lose its magnetism because the domains are moved out of line.

98. GALVANOMETER (II)

Materials: A lecture-table galvanometer (Science Kit #65958 for $261.00 or Cenco No. 82136-000).

Procedure: The galvanometer is encased in clear plastic so students can see how it works. Point out the needle hooked to the armature between a horseshoemagnet. There are probably inexpensive galvanometers that have actions that are visible.

99. ELECTRIC MOTOR (II)

Materials: Electric motor (Science Kit #62629-95 for $127.25 or Sargent Welch 2468). These electric motors can be taken apart to show students how they work and the various parts which comprise it. The iron core, field coil and commutator can be examined. The motor will run on a.c. or d.c. power.

100. LOUDSPEAKER (I)

Materials: An old loudspeaker.

Procedure: Take the loudspeaker apart so students can see how it operates. As the sleeve is moved back and forth on a magnet, a diaphram is moved to produce sound waves by changing the air pressure around it.

101. GALVANOMETER TO SHOW EMF PRODUCED BY MAGNET (II)

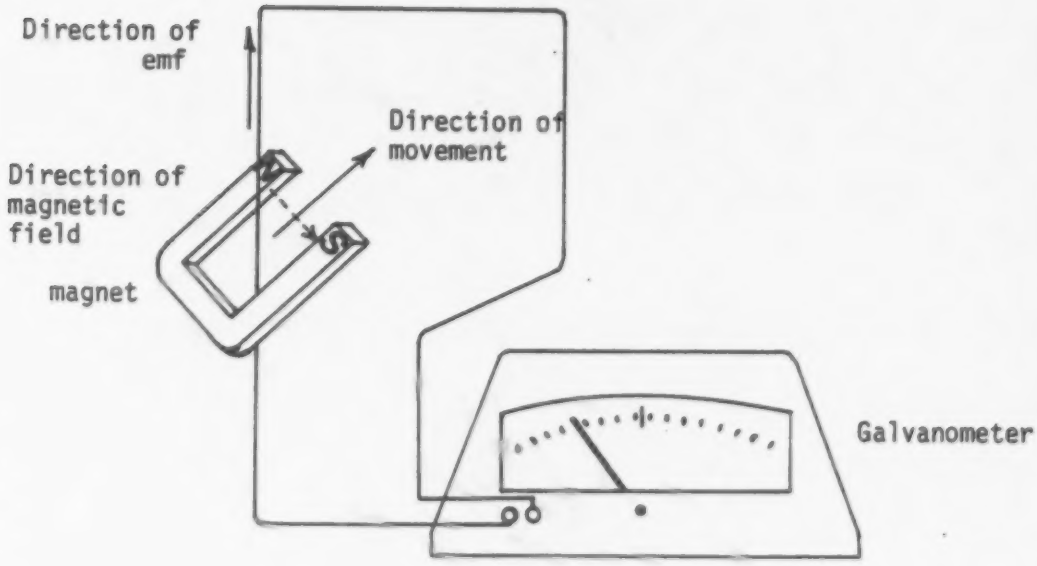
Materials: A galvanometer, a coil of wire and a bar magnet.

Procedure: Connect the wire coil to the galvanometer and move the bar magnet into the coil; the galvanometer will show that an emf is produced. Move it in and out, fast and slow, reverse sides to show different effects.

101A. THE GENERATOR EFFECT (I)

Materials: A strong horsehoe-shaped permanent magnet, galvanometer, connecting wire.

Procedure: Use the wire to make a circuit that contains only the galvanometer. Move a length of the wire between the poles of the magnet. Use various orientations of the wire and various speeds. Notice the deflections produced on the galvanometer.



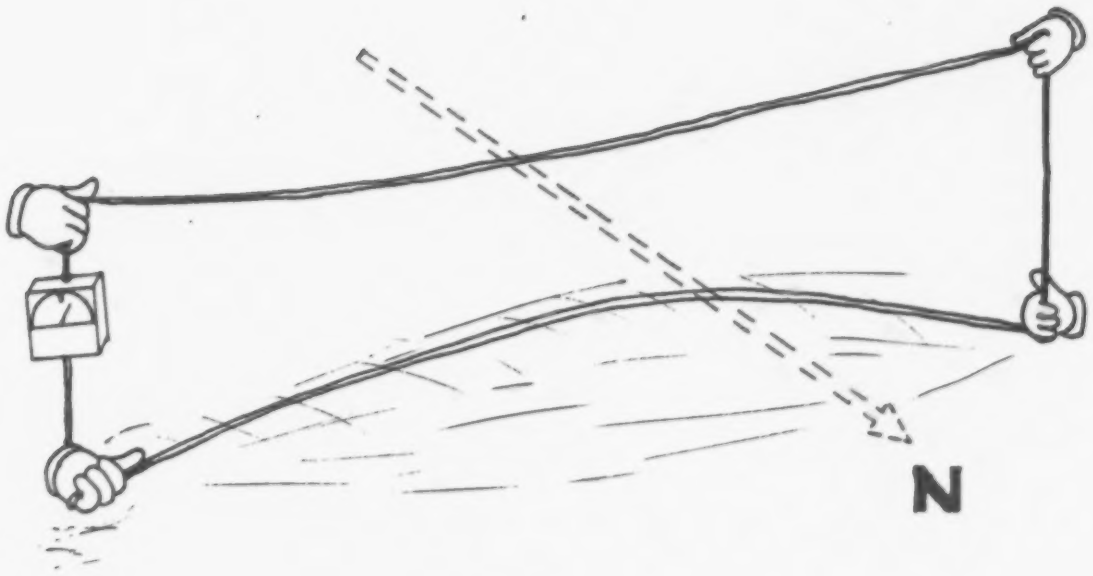
101B. THE EARTH'S MAGNETIC FIELD* (I)

Materials: A 50-ft. extension cord, 2 alligator clip leads, a galvanometer.

Procedure: Attach each end of the extension cord to the galvanometer, using a clip lead. Use two people to support the extension cord and form a single large loop, roughly rectangular in shape. Orient the loop so that a line drawn perpendicular to the face of the loop would point north or south. With one person holding the end of the cord that comprises the lower side of the rectangular loop, the other person whirls this portion over-an-over in a loop, as in a game of jump-rope.

The changing area of the loop causes a changing flux due to the earth's magnetic field. The current produced deflects the galvanometer.

*Credit to D. Rae Carpenter and Richard B. Minnix, Virginia Military Institute, Lexington, VA.



102. ARMATURES (I)

Procedure: Collect several old armatures and show them to the class so that they can see different sizes and types of construction.

103. HAND TURNED GENERATOR (II)

Materials: A hand turned generator (Fisher Scientific #S43574 for $53.06).

Procedure: Connect a galvanometer to the generator; as it turns, students can see that an emf is produced.

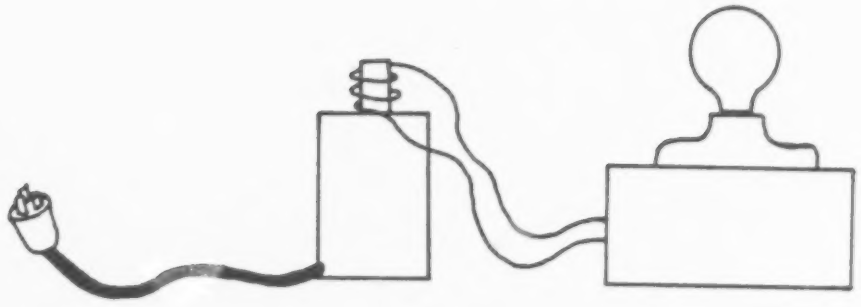
104. ELECTROMAGNETIC EFFECTS (II)

Materials: Elihu-Thompson type of electromagnetism apparatus (Cenco No. 79835-000 for $495.00). This apparatus is a coil with a core that can be moved in and out. The coil is connected to a 120-volt a.c. receptacle.

Procedure: With the core in, place a coil of wire connected to a small light bulb near the tip. The bulb lights because of the induced current.

Raise the core. Wrap a length of wire, connected to a bulb, around the core. As more turns are added, the bulb gets brighter.

Put a metal ring over the raised core. When current is supplied to the coil, the ring will jump several feet straight up. This shows that electric energy is transformed into magnetic energy and magnetic energy is then transformed into mechanical energy.



PART II

LABORATORY

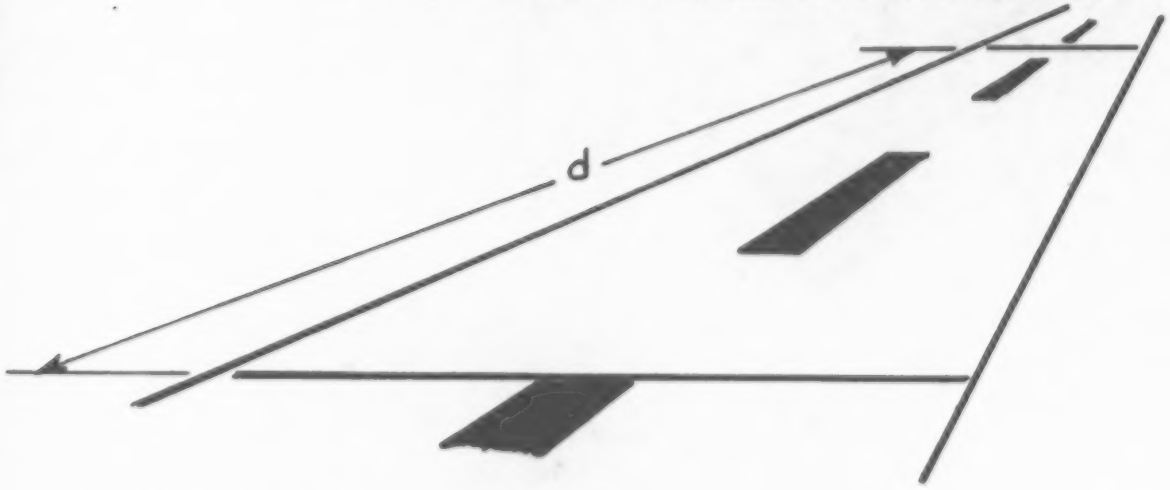
EXPERIMENTS

1. MEASUREMENTS OF SPEED AND DISTANCE (I)

Purpose: To obtain familiarity with the concepts and measurements of distance and average speed.

Materials: Stopwatch, measuring tape or meter stick.

Procedure: Measure the distance between two arbitrary points on a nearby road. Determine the elapsed time of automobiles, bicycles, or pedestrians that pass between the two points. Obtain average speeds for three or more different objects. Express answers in feet per second and then convert to miles per hour.



2. USING ACCELERATION OF GRAVITY TO CALCULATE REACTION TIMES (I)

Purpose: To study the acceleration of gravity by using it to calculate reaction time.

Materials: One dollar bill, meter stick.

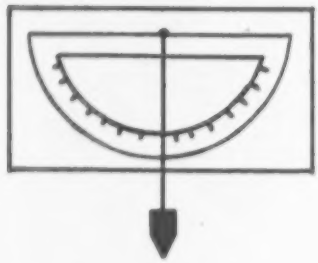
Procedure: Hold a dollar bill lengthwise, so that it hangs vertically between another person's thumb and forefinger, placed about halfway up the dollar bill. Drop the bill. The other person cannot catch it, since his reaction time is too long. To calculate his reaction time, repeat the experiment several times using a meter stick or ruler in place of the dollar bill. Test different students. Record the distance the meter stick travels before the person can catch it. Average distances for each person and and use the formula $\Delta x = \frac{1}{2}at^2$ to calculate the reaction time for each person.

3. MEASUREMENTS OF HEIGHT AND THE ACCELERATION OF GRAVITY (I)

Purpose: To gain experience in making measurements, to make practical use of trigonometry, to experience the constancy of g, and to learn how to report error in experiments.

Materials: One 6-inch protractor, block of wood, measuring tape, assorted objects to drop.

A. Procedure: Measurements of Height Using a Protractor.
Attach a small protractor to a block of wood. Attach a plumb line from the hole in the midpoint on the bottom rule of the protractor and let it hang down over the protractor scale. Line up the straight ruled edge of the protractor by sighting at the top of the building you are determining the height of. The angle between the plumb line and the 90° mark is the angle of elevation. Record this angle; measure the distance to the building and use the tangent of that angle and the measured distance to determine the height of the building. Be sure to add your height to the calculated height from eye-level to calculate the total height.



B. Procedure: Investigation of Falling Objects.
Obtain at least four objects (some heavy, some light) made of different materials. Drop the objects from a high building or window, two at a time, simultaneously. Observe whether they strike the ground simultaneously.

C. Procedure: Drop from the window or building top a single heavy object and measure the time with a stopwatch. Measure the height of the window as in part A. Use these measurements to calculate the acceleration due to gravity from $d = \frac{1}{2}gt^2$. It is good training in error analysis to determine g five times and calculate the sandard deviation and the standard deviation of the mean. (See the discussion under Experiment 16.)

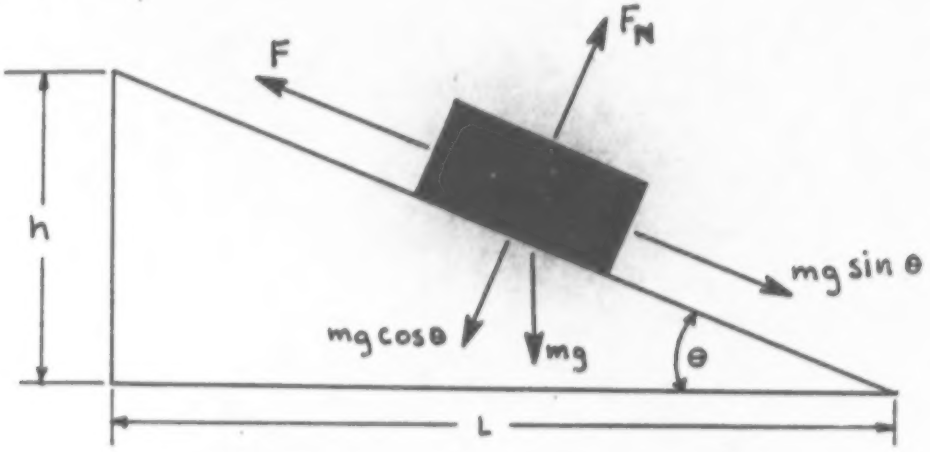
D. Procedure: Use the textbook value of g and make time measurements to calculate the height of the window from $h = \frac{1}{2}gt^2$. Compare the value of h from part A.

4. COEFFICIENT OF FRICTION (I)

Purpose: To study friction, the factors that influence it, and to study the coefficient of friction. Also, to determine coefficients of friction for several surfaces.

Materials: Spring balance, different types of rigid flat surfaces, meter stick, weights, a wooden block with hook, and a metal block with hook.

A. Procedure:

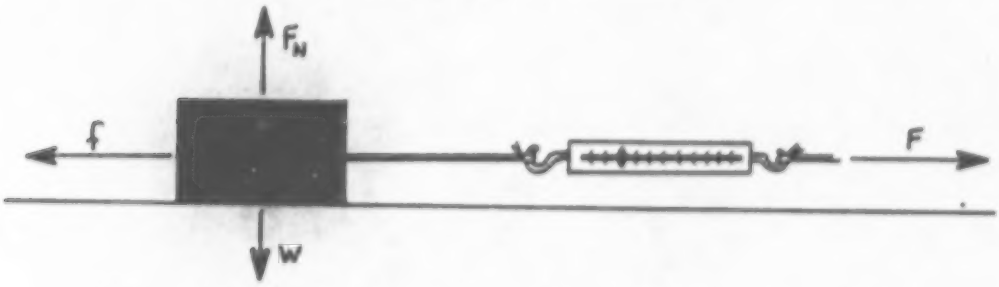


If θ is increased until the object will just slide without accelerating, then $f = mg \sin \theta$, where f is the frictional force. The coefficient of friction μ is defined by $\mu \equiv \frac{f}{F_N}$. Since $F_N = mg \cos \theta$, $\mu = \frac{mg \sin \theta}{mg \cos \theta}$, or $\mu = \tan \theta$. Therefore, we can determine μ by allowing the block to slide at a uniform speed down an incline. The angle can be determined either by using an incline equipped with a protractor or by simply elevating a smooth board at one end by some means.

L	h	$\mu = \tan \theta = h/L$

COEFFICIENT OF FRICTION (continued)

B. Procedure: Since $\mu = \frac{f}{F_N}$, we can find μ by determining the values of the frictional force f and F_N. Attach a spring balance to the object and pull the object at a constant speed, making sure that the spring balance is held parallel to the surface.



Since the object is moving at a constant speed, F = f.

W	F_N	F	f	$\mu = f/F_N$

At this point the student should compare the two values of μ.

To add interest:

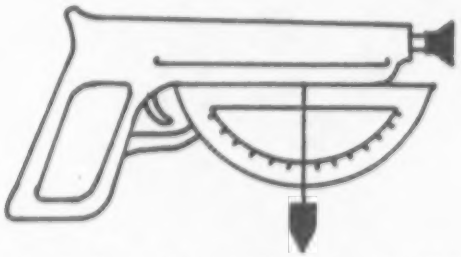
1. Different weights could be used in part B to illustrate the independence of μ and weight. Use weights up to 100 pounds.
2. Different surfaces and objects could be used in parts A and B to show the relationship between μ and the nature of the materials.
3. Observations should be made in part B and comparisons should be drawn between "starting" friction and "moving" friction.
4. Students should devise means of changing f and μ, such as lubrication, waxing, smoothing surfaces. The instructor can offer rewards for students who bring in the slipperiest or roughest surfaces to be measured.

5. PROJECTILE MOTION (I)

Purposes: To teach the concepts involved with projectile motion.
To calculate the range of a projectile.
To learn the relationship between muzzle velocity, angle of elevation, and range.

Materials: A spring-action dart gun, darts, meter stick, one 4-inch protractor, clamp, string, weight, one number 8 rubber stopper.

A. Procedure: Using the string, weight and protractor, make a transit and glue it to the dart gun so that you will be able to determine the angle of elevation of the barrel.



B. Procedure: Remove the suction cup from the dart and substitute a stopper, such as a number eight. This adds weight and reduces the dart range to a convenient value. Clamp the gun so that the barrel is perpendicular to the floor. Fire the dart toward the ceiling. By measuring the distance h of the barrel from the ceiling when the dart barely reaches the ceiling, determine the muzzle velocity:

$$v^2 - v_0^2 = 2ah$$

$$v = 0,\ a = -g$$

$$\therefore\ v_0 = \sqrt{2gh}$$

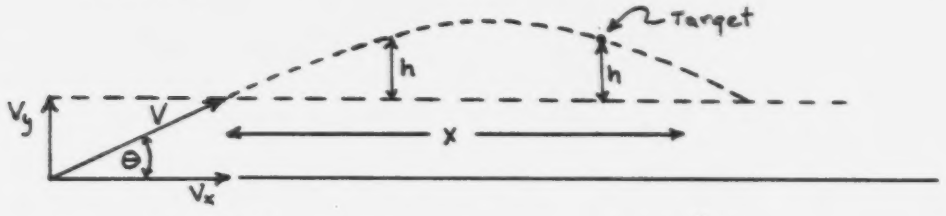
C. Procedure: Now clamp the dart gun at various angles and calculate the angle required to fire the dart into a trash can a specified distance away (at the same altitude).

$$\Delta x = \frac{v^2 \sin 2\theta}{g}$$

The derivation of this equation should be assigned to a good student. Use $2 \sin \theta \cos \theta \equiv \sin 2\theta$.

PROJECTILE MOTION (continued)

D. Procedure: Variations: Place the target at levels above and below the level of the barrel. For a given altitude and range, have students calculate the angle of the gun needed to hit the target. Have them derive an equation showing the relationship among the angle of elevation, the height and the range. Have "wars" between teams. A team is eliminated when an opposing team successfully fires a dart into a trash can stationed by that team. (No shot can be fired until the angle or range is calculated.)



$s = v_0t + \frac{1}{2}at^2$ $\qquad t = \frac{x}{v_x}$

$h = v_yt - \frac{1}{2}gt^2$ $\qquad t = \frac{x}{v \cos \theta}$

$h = v \sin \theta t - \frac{1}{2}gt^2$ $\qquad h = (v \sin \theta)(\frac{x}{v \cos \theta}) - \frac{1}{2}g(\frac{x}{v \cos \theta})^2$

$$h = x \tan \theta - \frac{gx^2}{2v^2 \cos^2 \theta}$$

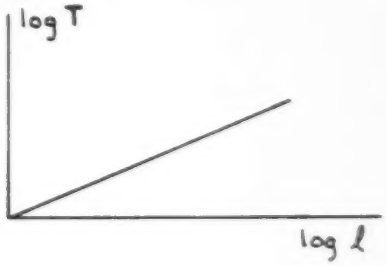
6. THE SCIENTIFIC METHOD APPLIED TO THE PENDULUM (I)

Purposes:
(1) To illustrate the use of the scientific method in gathering data.
(2) To use mathematical methods in analyzing data in order to see relationships between variables.
(3) To formulate some relationship between various variables and the period of a pendulum.

Materials: Pendulum clamp, string, weights, stopwatch, weight platform, meter stick, protractor.

Procedure: Clamp a string by means of the pendulum clamp. Tie the weight platform to the free end. Note the mass of the platform and add a known mass to it. Time twenty complete vibrations to determine the period. Measure the length of the pendulum from the axis of oscillation to the center of mass of the weights. Repeat several times, varying the following factors one at a time: (1) the mass, (2) the length of the string, (3) the amplitude of the arc.

In examining the data, one finds that the period is independent of the mass of the pendulum bob and of the angle of displacement, so long as the angle is small (15° or less). The period is dependent on the square root of the length of the string. This is seen by plotting the log of the length versus the log of the period. One gets a graph as follows:



The slope is 0.5; therefore

$$\log T \propto .5 \log \ell.$$

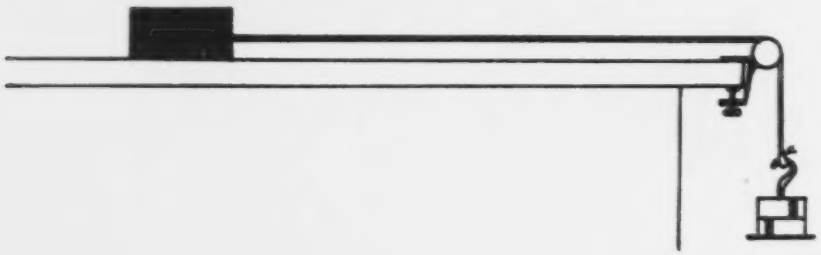
Then $T \propto \sqrt{\ell}$.

7. NEWTON'S SECOND LAW ON A HORIZONTAL PLANE (I)

Objective: To see the relationship among mass, acceleration, and unbalanced force.

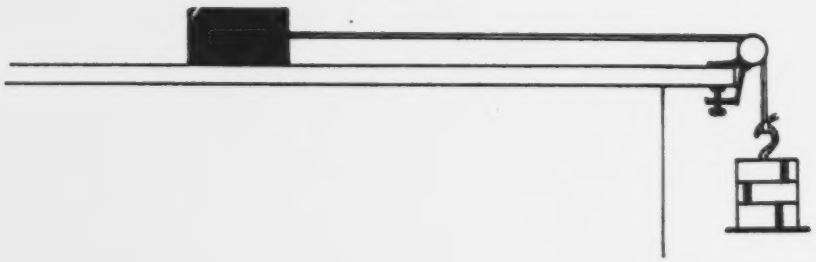
Materials: Hall's carriage (CENCO 75850-000, $13.50), pulley, string, meter stick, weights, weight platform, board.

A. Procedure: Determine the coefficient of friction.
Set the equipment up as follows:



Add weight to the platform until the carriage will move across the board at a constant velocity. Record this weight as the frictional force. Weigh the Hall's carriage. This weight is equal to the normal force. Calculate μ for the system.

B. Procedure: Relationship of unbalanced force to acceleration.
Put more weights on the platform so that there is an unbalanced force on the carriage and calculate the theoretical acceleration. In several trials, time the movement of the carriage from one end of the board to the other.



As the time measurement is the primary source of error, use a long board, if possible. Also, use as much weight in the carriage as is practicable.

C. Procedure: Relationship of mass to acceleration.
Place several weights on the carriage to increase its mass. Determine the additional frictional force due to the increased normal force. Add this additional weight to the weight platform so that unbalanced force will remain constant. Repeat the timing of several trials as in part B.

8. NEWTON'S SECOND LAW ON AN INCLINED PLANE (I)

Purpose: To study F = ma by using it to predict the acceleration of an object.

Materials: Hall's carriage (CENCO 75850-000, $13.50), board, meter stick, stopwatch (Cenco 73512-000, $45.00), weights.

A. Procedure: Find the coefficient of friction. Place the Hall's carriage on the board and tilt the board until the carriage moves freely at constant velocity down the board. Measure the length and height of the board and calculate μ.

Sample Data

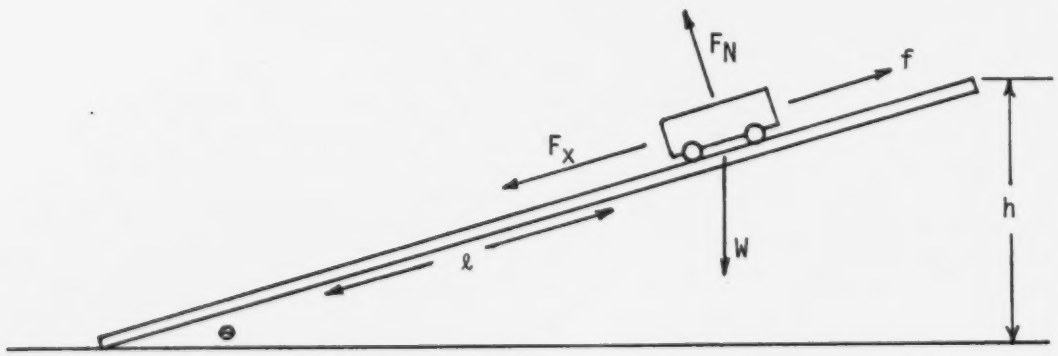
ℓ	h	$\theta = \arcsin \frac{h}{\ell}$	$\mu = \tan \theta$
72.8cm	.79cm	.62°	.0108

B. Procedure: Find the theoretical value of acceleration. Tilt the board to a higher angle, which is ascertained by using the new height. Draw a force diagram and compute the unbalanced force acting on the carriage. Determine the acceleration.

Sample Data

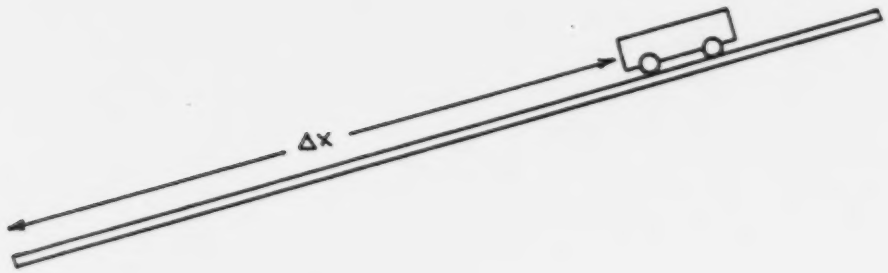
	ℓ	h	θ	m	W	F_x	F_N	f	F_{net}	a
1.	72.8	5.1	3.9°	3.966	38.9N	2.6N	38.8N	.42N	2.2N	.55m/s^2
2.	72.8	20.5	16.4°	3.966	38.9N	11.0N	37.3N	.40N	10.6N	2.67m/s^2

where $F_{net} = F_x - f$



NEWTON'S SECOND LAW ON AN INCLINED PLANE (continued)

C. Procedure: Measure the acceleration.
Release the car and time its descent. Measure the actual distance that the car moves.



Δx	t	a	Error	% Error
58 m	1.5 s	.52 m/s²	.03 m/s²	5%
58 m	.65 s	2.74 m/s²	.07 m/s²	2.6%

9. ESTIMATION OF MASS AND LENGTH (I)

Purpose: To develop students' intuition for metric units of mass and length.

Materials: Scales, weights, meter stick, centimeter rule, assorted objects.

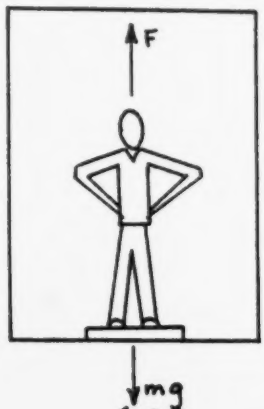
Procedure: Divide students into teams of two each. Each team determines the mass and lengths of various objects. The teams then challenge each other to guess the predetermined values of the masses and lengths. Points can be given for each correct guess. Allow 50% error for length and 100% error for masses. Team members alternate guesses.

10. ACCELERATION OF AN ELFVATOR (I)

Purpose: To use F = ma to determine the acceleration of an elevator.

Materials: Elevator, bathroom scales.

Procedure: Stand on the bathroom scales in a motionless elevator. Start the elevator upward. Notice that the scale reading increases. Record this reading. Calculate the acceleration from F - mg = ma. Repeat for downward acceleration.

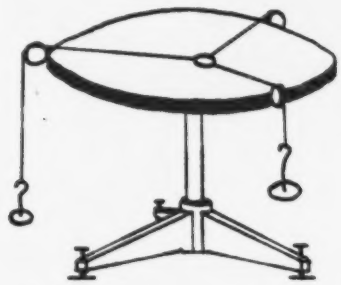


11. EQUILIBRIUM: CONCURRENT FORCES (II)

Purposes: To practice working with forces as vectors.
To practice resolving force vectors into components and calculating the resultant and equilibrant forces.
To demonstrate the conditions necessary for equilibrium.

Materials: Force table, string or strong thread, several weights, meter stick, pole and pole clamps, spring scale.

Procedure: Consider two forces, F_1 and F_2, which act on a single point and which make angles θ_1 and θ_2 from the x-axis. Set this up using the force table by suspending two weights from the center of the table over the side. Record the magnitude of the forces and the angles θ_1 and θ_2 that the forces make with the x-axis. Pick an angle θ_3 and predict the magnitude of a third force, F_3, which will be required for equilibrium when applied at θ_3.



After determining the magnitude of this "equilibrant" force, experimentally verify this by suspending a weight of the calculated magnitude at the angle θ_3.

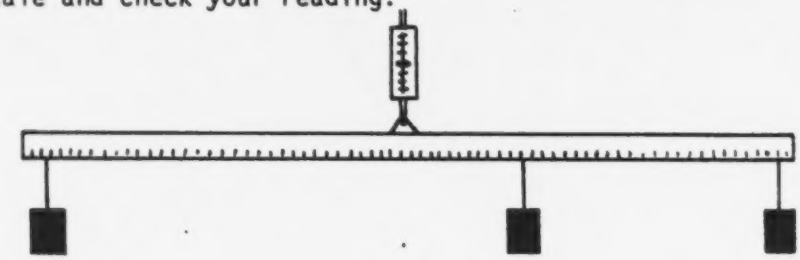
Force tables are available commercially. They can be made in a shop, as they consist of a circular "table" that is twelve to sixteen inches in diameter. Angles from 0° to 360° should be marked and labeled. The weights are tied to three strings, which are tied to a ring. The ring can fit over a vertical post at the center of the table.

12. EQUILIBRIUM AND TORQUE (I)

Purposes: To show that for a system in translational equilibrium the first condition of equilibrium must be met.
To show that for a system in rotational equilibrium the second condition of equilibrium must be met.
To become familiar with the concept of center of mass.

Materials: Balance, meter stick, 2000-gm spring scale, ring stand with clamps, meter stick clamps to hang weights on, hanging bracket weights.

A. Procedure: Determine the mass of a balanced system of your choosing. Be sure to include the clamps and the meter stick. Use the balance for this determination. Then hang the system from the spring scale and check your reading.



Is the system in equilibrium? Does the upward force equal the downward force?

B. Procedure: Arrange a balanced system of your choosing. Hang the meter stick through from the middle for this part. Determine the clockwise torques and the counterclockwise torques. Be sure to include in each torque determination the mass of the meter stick clamps. The mass of the meter stick can be said to be concentrated at the center of gravity, which is the axis of rotation.

C. Procedure: Predict the length of a torque arm. Arrange a system that is unbalanced and which is not hung at the center of the meter stick but may be 10-20 cm off from the center. Determine where on the meter stick a certain mass will have to be hung in order to balance your system. Compile data as you consider appropriate.

13. GRAPHICAL ANALYSIS OF ONE-DIMENSIONAL MOTION (I)

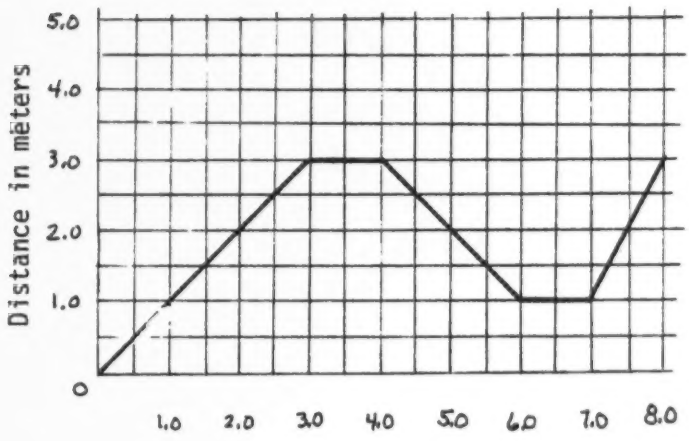
Purpose: To better understand graphical interpretations of displacement and velocity.

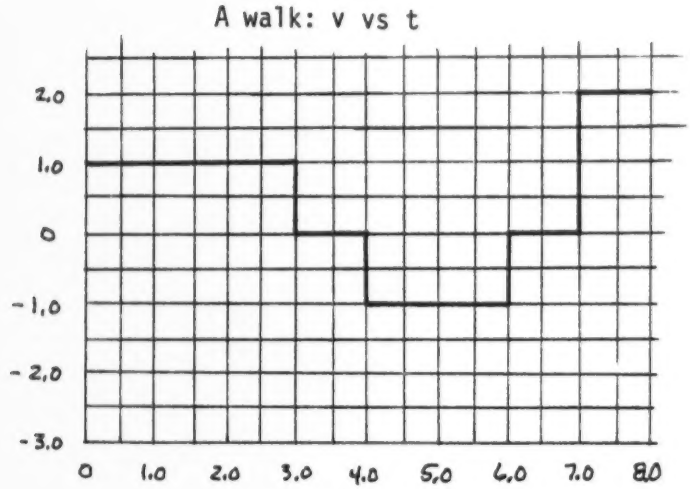
Materials: Stopwatch, meter stick or measuring tape, graph paper.

Procedure: Let students work in teams. Each team designs a one-dimensional motion up and down a long hall. A position-versus-time graph is then drawn for the motion. The slope of this curve yeilds a velocity-versus-time graph.

Teams exchange velocity-versus-time graphs. The team wins which first walks the path designed by the other team and draws the corresponding position-versus-time graph.

Example:





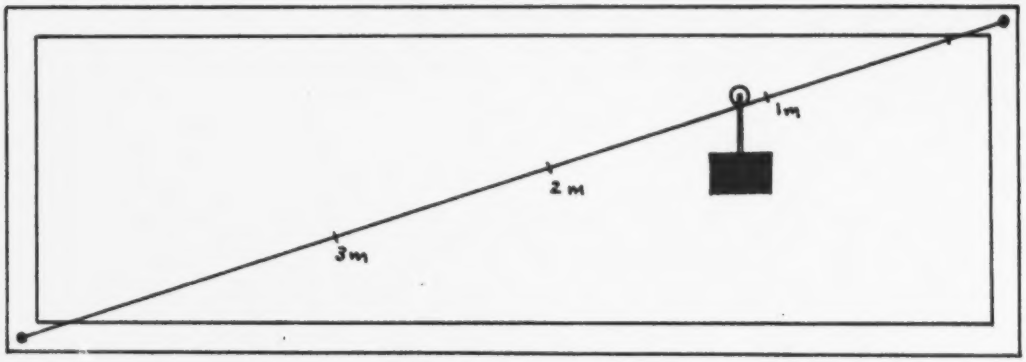
14. CONSTANCY OF THE ACCELERATION OF GRAVITY (I)

Purpose: To repeat Galileo's experiment showing that the acceleration of an object on an incline is constant. Reference: Foundations of Modern Physical Science, Holton and Roller, pp 28-32 (Addison-Wesley).

A. Variation 1:

Materials: Wire, pulley, stopwatch, weights, screws, screwdriver.

Procedure: Put screws into opposite corners of the frame of a large chalkboard. Stretch a wire tightly between the two screws and let a pulley (or small car with frictionless wheels) ride along the wire.

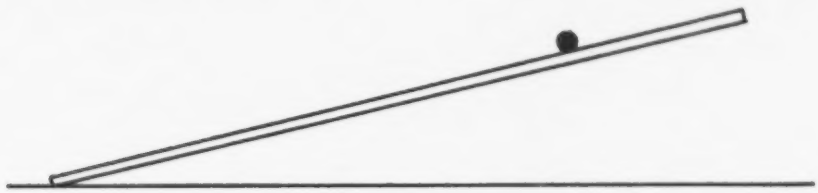


Mark positions on the chalkboard and measure time required for the pulley to move 1, 2, 3, and 4 meters. The acceleration of gravity can be calculated from $a = g \sin \theta$. (If the moment of inertia of the pulley is negligible, rotational effects will be insignificant.) If g is constant, then the equation $d = 1/2\ at^2$ predicts that the quotient $\frac{d}{t^2}$ will be the same for all intervals.

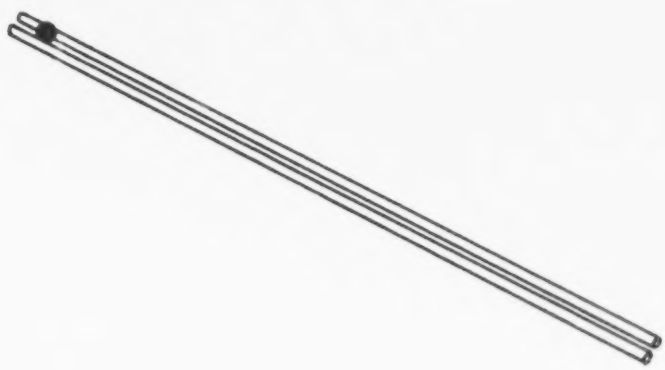
CONSTANCY OF THE ACCELERATION OF GRAVITY (continued)

B. Variation 2:

Materials: Stopwatch, meter stick, heavy marble, long, smooth ramp with a V-shaped groove. The ramp can be a piece of aluminum or steel from a machine shop.



Or, it can be formed from two steel rods such as those commonly used as table stands in science laboratories. If these are not available, merely a smooth board will suffice.



Procedure: Use various angles and time the descent of the marble for various distances down the incline. For a given angle, $\frac{d^2}{t}$ should be constant. For example, if two distances d_1 and d_2 are chosen such that $d_1 = 1/4\ d_2$, then the times should be related by $t_1 = 1/2\ t_2$.

The equation $d = 1/2\ at^2$ can be used to find the acceleration, and the acceleration of gravity, g, can be calculated from $a = g \sin \theta$. This relationship ignores rotation and can be expected to introduce noticeable error in the value obtained for g. On the other hand, the constancy of a (and therefore g) can be ascertained with considerable accuracy.

15. CENTRIPETAL FORCE (I)

Purpose: To measure the relationship of centripetal force, mass, and velocity.

Materials: Glass tube, 15 cm long and at least 1 cm in outside diameter, masking tape, nylon fishing line, rubber stopper, set of weights, paper clip, stopwatch or watch with a second hand.

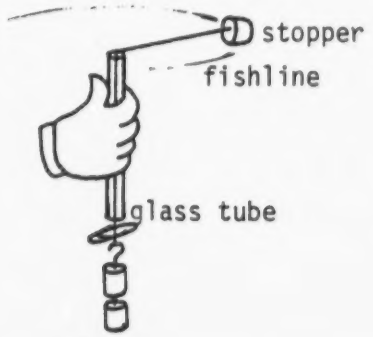
Procedure: Cut a 1.5-m length of fishingline and fasten one end of it securely to the rubber stopper. Fire polish the ends of the glass tube so that the line will not be cut when the weight is whirled. Also, cover the glass tube with masking tape to prevent breakage during the experiment. Feed the line through the glass tube. Fasten a 50-g weight to the free end of the line. Adjust the line so that there is about 1.0 m between the top of the tube and the stopper. Fasten a paper clip to the line just below the bottom of the tube.

Support the 50-g weight with one hand and hold the glass tube in the other. Whirl the rubber stopper by revolving the tube. Slowly release the 50-g weight and adjust the speed of the revolution so that the paper clip stays just below the bottom of the tube. Make several trial runs before recording any data.

When you have learned how to keep the rotational velocity and position of the paper clip constant, have a second person measure the time required for 30 or 40 revolutions; calculate the time for a single revolution. Record the centripetal force (The centripetal force is just the tension force on the stopper by the string. This is equal to the weight of the 50-g weight.) and velocity (calculated from the radius and the period of revolution).

Repeat the procedure, but increase the centripetal force by adding 20 g to the 50-g weight. Record the resulting data. Run a third trial by adding still more weight.

Graph: Plot a graph of the data, using F as abscissa and v as ordinate. Plot a second graph of the same data, using F as abscissas and v^2 as ordinate. If time permits, run a series of trials in which (1) the radius is kept constant, but the mass of the whirling object changes and (2) the mass of the object is kept constant, but the radius changes. Record the appropriate data and plot graphs to show the relationships.



16. RESONANCE OF A CLOSED AIR COLUMN (I)

Materials: A three-foot piece of transparent or transluent glass or plastic tubing (3/4 to 1 inch diameter), a rubber hose, a can or cup with a hole in the bottom, a 512-Hz or 1000-Hz tuning fork, and a stand.

Procedure: Mount the tube vertically with the tuning fork mounted just over the upper end. The rubber hose connects the lower end of the tube to the can or cup. With the cup near the floor, fill the tube with water. Raising and lowering the cup then raises and lowers the water level in the glass or plastic tube, providing a closed air column of variable length.

Strike the tuning fork and raise or lower the water level until a maximum loudness is heard. This corresponds to a resonance. The length of the tube L above the water level and the wavelength of the sound λ are related by $L = \frac{n\lambda}{4}$, where n = 1, 3, 5, etc.

Mark the position of the resonance on the tube with a rubber band. Change the water level until another resonance is heard. The distance between adjacent resonances is $\frac{1}{2}\lambda$. The known frequency f of the tuning fork can then be used in the equation $v = f\lambda$ to calculate the speed of sound.

Repeat the procedure five times; change tuning forks if a second one is available. Calculate the average or mean speed $\bar{v}$ for the five trials and then calculate the standard deviation, s, defined by

$$s = \sqrt{\frac{\sum_1 (\bar{v} - v_1)^2}{N - 1}} \quad .$$

From this, calculate the standard deviation of the mean, σ, defined by

$$\sigma = \frac{s}{\sqrt{N}} \quad .$$

This is taken to be the "error" (assuming that there are no sources of systematic error present), so that the "true" speed is

$$v = \bar{v} \pm \sigma \quad .$$

For comparison, use the speed of sound as 331 m/s at 273 K and calculate the speed at your room temperature from

$$\frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}} \quad .$$

See No. 42, Part I, for the diagram.

17. THIN LENSES (I)

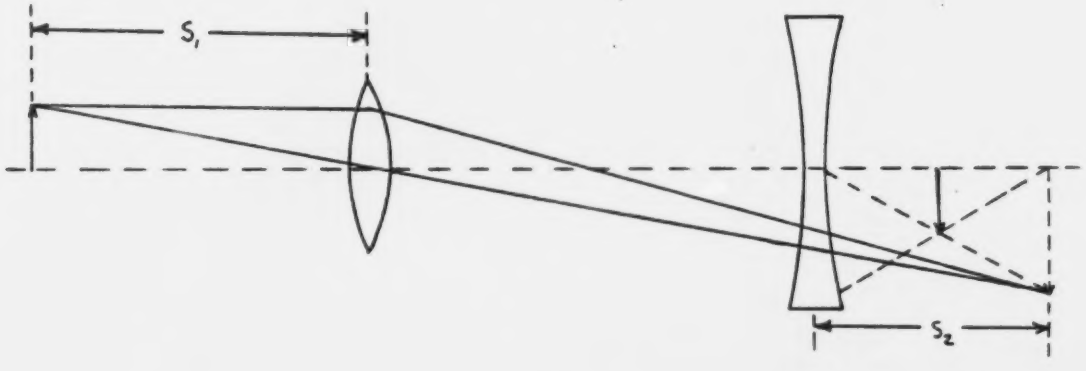
Materials: Each student needs one converging lens and one diverging lens, a light source, and two small pieces of styrofoam to serve as lens holders. (Merely stick the lens into a hole punched into the styrofoam.)

A. Procedure: In a darkened room, with one shade raised a few inches, project the image of a distant landscape through a converging lens onto a white screen a few centimeters away. The position from the lens to the screen, when the image is in focus, is the focal lenght of the lens.

B. Procedure: Position the converging lens an arbitrary distance from the light source. Calculate the position of the image. Use a sheet of white paper to locate the image and compare the position with the calculated value.

C. Procedure: Place the diverging lens between the converging lens and the image of the converging lens. The distance between the diverging lens and the image of the converging lens can be taken as the (virtual) object distance of the diverging lens, and it will have to be considered negative. The position of the (real) image of the diverging lens can be measured, and the focal length of the diverging lens can then be calculated. (Put a piece of white paper at the position of the image to see it.)

This lens system, therefore, has a real image.



The distance of the object from the convex lens is s_1. The virtual object for the diverging lens is at a distance s_2 from the lens.

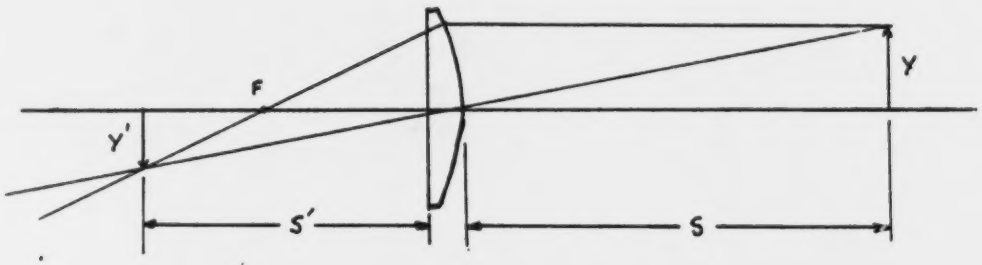
17A. MEASURING THE SIZE OF A DISTANT OBJECT USING GEOMETRIC OPTICS (I)

Purpose: To study the properties of thin convex lenses.

Materials: A convex lens.

Procedure: If the distance to an object is known, the dimensions of that object can be determined by forming an image of that object and measuring the dimensions of the image. If the focal length of the lens is known, then the object size can be calculated.

The magnification of an object is given by the equation $M = \frac{s'}{s}$, where s' is the image distance and s is the object distance. Also, the magnification is defined by $M = \frac{y'}{y}$, where y' is the image size and y is the object size. If the object distance is very large compared to the focal length, we can use the focal length for s'.

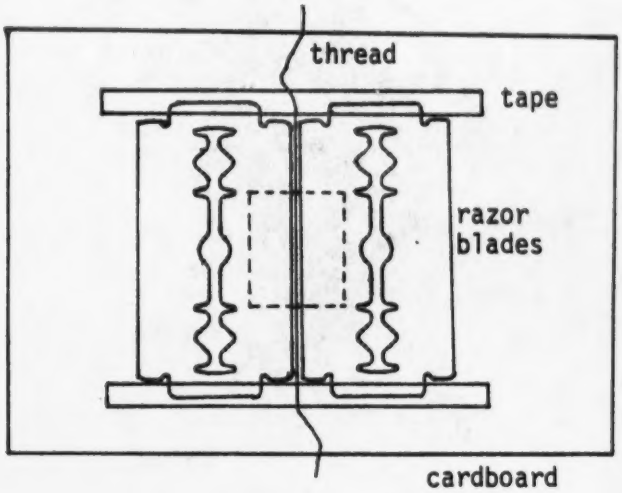


Focus the image of a distant object such as a streetlight or a tree on a piece of graph paper. When the image is focused, carefully mark the top and bottom of the image on the paper. Measure the distance between the marks; this is the value for y'. Using the known values for f and s, calculate the size of the distant object.

17B. INTERFERENCE AND DIFFRACTION OF LIGHT*(I)

Purpose: To show that light diffracts when it goes through small openings, and to demonstrate the interference pattern of a double slit.

Materials: Razor blades, cardboard, narrow light source, red, blue and green filters.



Procedure: To make a double slit, cut a square of cardboard about 10 cm on a side. Then cut a 2 cm square in the center. Tape a piece of heavy thread across the hole and then tape a razor blade on each side of the thread.

To make a single slit, follow the same procedure but omit the thread.

Hold the single slit vertically near one eye and look at the narrow light source placed at a distance of three meters. Describe what you see.

Repeat this procedure with a red filter in front of the light. Then do the same with the blue and green filters.

Follow the same steps with the double slit. Describe what you see.

Explain in detail the evidence that light has wave properties.

*Stollberg and Hill, Physics Fundamentals and Frontiers, p. 497, Houghton and Mifflin, Boston, 1980.

18. ATTRACTIVE ELECTROSTATIC FORCES (I)

Materials: Each student or pair of students is given the procedure and a plastic bag that contains the following items: a vinyl strip approximately 1 inch wide and 8 inches long, patches of wool and other cloths, small pieces of assorted materials such as paper, cork, aluminum foil, rubber, etc.

Students can work either individually or in pairs. They should be free to confer and compare results.

A. Procedure: First, hold the vinyl strip above a small bit of paper. Does anything happen? Rub the strip with the wool cloth. Touch several different things and write down what happens. Note that, after a few minutes, the effect wears off. Pick up as many pieces linked together as you can. Are the pieces attractive if you remove them from the strip? Is the cloth also attractive? Does the strip ever exert a repulsive force? How can you make the strip lose its attractive effect? Which items are easier to pick up? Which ones harder? Is it necessary to touch an object to exert a force on it? Does the strip attract only certain kinds of materials, or does it attract conductors as well as insulators?

B. Procedure: Use another cloth and repeat.

C. Procedure: Use the plastic bag to rub the strip and see what happens.

D. Procedure: After repeated uses, does the strip lose its ability to attract? Why?

E. Procedure: Is the force of the strip on a piece of paper as large as the force of the Earth on the piece of paper?

F. Procedure: Come up to the front of the room, rub the vinyl strip, and put it near a stream of water from the faucet.

19. REPULSIVE AND ATTRACTIVE ELECTROSTATIC FORCES (I)

Materials: Each student (or pair of students) is given the procedure and a plastic bag containing the following items: a vinyl strip as in Experiment 18, a similar strip made of acetate, a wool cloth, and a graphite-covered pith ball with a thread attached.

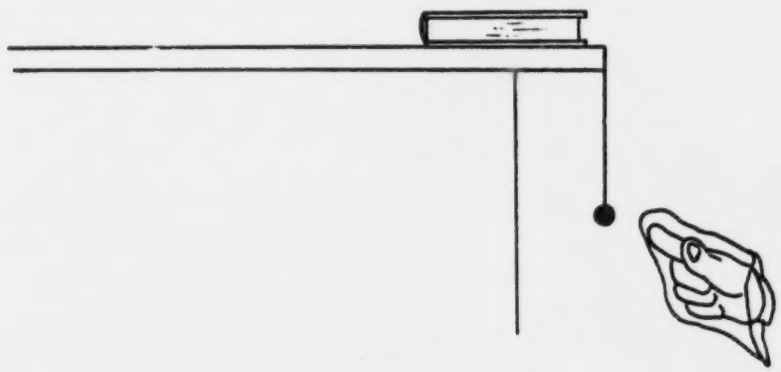
Students can work in pairs or they can work singly and compare their results as they proceed.

A. Procedure: Suspend the graphite-covered ball over the edge of your desk by placing the free end of the string under your book. Rub the acetate strip with the plastic bag (wear it as a glove) and hold it near the ball. Is there a force on the ball? Is it attractive or is it repulsive (a push)?

B. Procedure: Under what circumstances can the strip exert an attractive force? When does it exert a repulsive force?

C. Procedure: Rub the acetate strip and make it repel the ball. Now hold the plastic bag near the ball. Does it exert a force? What kind?

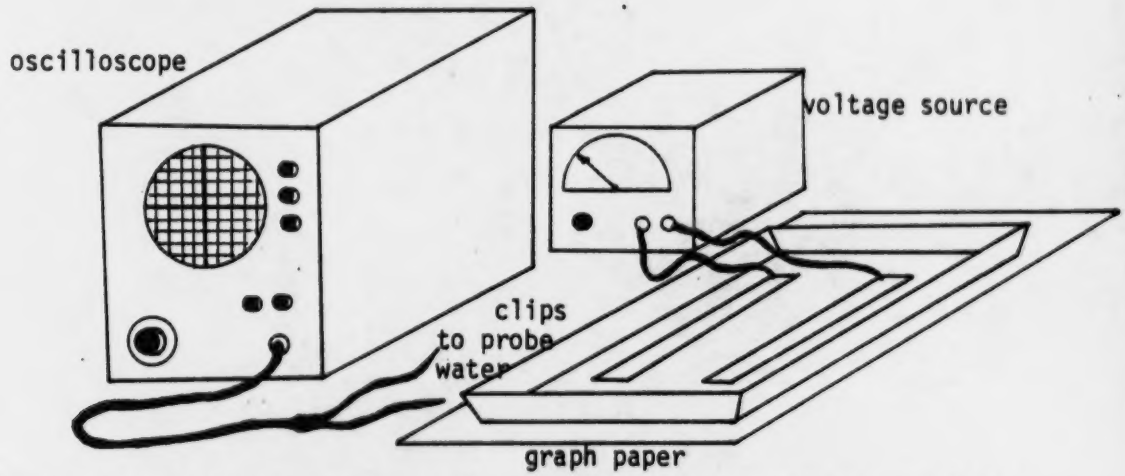
D. Procedure: Again repel the ball with the acetate strip. Rub the vinyl strip with the wool cloth. Does it exert a force on the ball? What kind?



19A. THE ELECTRIC FIELD* (II)

Purpose: To plot equipotential lines in an electric field.

Materials: Clear pyrex pan with flat bottom, two metal bars or strips of sheet metal, 20-volt d.c. source or transformer with 120-V input and 20-V output, oscilloscope, lead wires with alligator clips, and two sheets of graph paper.



Procedure: Set up the apparatus as shown in the diagram. Place one sheet of graph paper under the pan for reference. Points are plotted on the other sheet.

Adjust the oscilloscope to get the sharpest possible image of a horizontal line. Place one of the oscilloscope leads at a point between the two metal bars. This will be a point on the first equipotential line. Plot this point on the graph paper.

With the other oscilloscope lead, locate points in the field that have the same potential as the initial point. You can observe this by watching the screen on the oscilloscope. Plot these points on the graph.

When enough points have been plotted, draw an equipotential line. The choose another starting point and repeat. Plot several equipotential lines in this manner.

Draw the positions of the metal bars on the graph paper. To show the electric field between the two pieces of metal, draw a line perpendicular to the position of one metal surface. Extend the line toward the other piece of metal. Cross each equipotential line perpendicularly. The line should end at the other metal object in a direction perpendicular to that surface.

Repeat the procedure six or eight times from different places on the surface of the first bar. These lines that are perpendicular to the lines of equipotential are the lines of force that depict the electric field.

*Stollberg and Hill, Physics Fundamentals and Frontiers, p. 269, Houghton and Mifflin, Boston, 1980.

20. INTRODUCTION TO ELECTRIC CIRCUITS (I)

Materials: Each student is given the instructions listed under Procedure along with a plastic bag that contains four or five connecting wires with alligator clips, nichrome wire (optional) if available (6 to 20 ohms per foot), two 6-V light bulbs and two bulb holders. In addition, each is given four flashlight D cells, and, if available, a holder in which they can be held together in series.

Procedure: (Students can work in pairs if necessary, but it is probably best that they work individually, as each one needs to discover the answers to the questions.) Follow the directions and answer the questions. Take your time, especially with the first step.

Take one battery out of the holder, and one or two insulated wires. Make the bulb light up. Draw the circuit showing the path of electrons in the circuit that (especially in the bulb) you constructed. Make your diagram large.

Examine the filament of the bulb. Is there a continuous conducting path between the two metal parts of the base?

Does it matter which part of the base is connected to which end of the battery? Try all combinations.

When the bulb is glowing, is the wire charged? How can you tell? Will it pick up a small piece of paper?

Put two batteries in the crease in your opened book. Use both batteries and make the bulb light.

Reverse the direction of both batteries. What happens? Trace the electron path for both configurations.

Reverse the direction of only one of the batteries and answer the above question.

Use an insulated piece of wire and see if current will pass if the contact is made with the insulation.

Put all 4 batteries in the battery box and a bulb into the bulb holder. Use all 4 batteries and make a circuit that will light the bulb.

Reverse connections. Does it make any difference? Does it matter if two of the batteries are reversed? If only one is reversed?

With all batteries in the box, use a paper clip or other piece of stiff wire as a probe to put first 1, then 2, then 3, then 4 batteries into the circuit. Describe what happens.

INTRODUCTION TO ELECTRIC CIRCUITS (continued)

Put 8 or 10 inches of tiny nichrome wire into the circuit. Be careful, the wire may get hot! Does the length affect the bulb brightness? Why?

Repeat above step with a one-half-inch length of wire and the bulb removed. (Be careful, it will get hot.) Why does the wire get warm? How could you build an electric heater? WHY DOES THE BULB GLOW? What is the purpose of the glass bulb around the filament?

Use two bulbs; make them both light up. If you take one bulb out of the holder, does the other go out? (If so, the bulbs are connected in "series".) Draw the circuit.

Connect two bulbs in such a manner that they don't go out if one is removed. Draw the circuit. How do the bulb brightnesses compare? The bulbs are said to be in "parallel." How are Christmas tree lights connected?

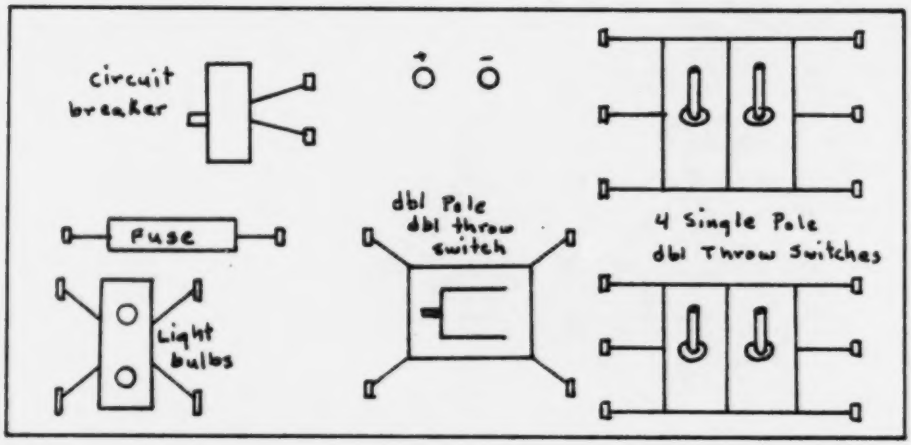
21. THE ELECTRIC CIRCUIT (II)

Objectives: To introduce students to different electric circuits.
To see how switches are wired.
To learn the purpose of fuses and circuit breakers.
To give students practice in wiring the different type circuits.

Materials: A 6-volt power source, single pole double throw knife switches (Science Kit #63110 - $2.75 each), double pole double throw knife switches (Science Kit # 63120 - $3.80 each), and several wire leads, a fuse, and small circuit breaker, and light bulbs.

All of these should be attahced to a wiring board.

DIAGRAM OF WIRING BOARD:



A. Procedure: In order for a battery to power a lamp, the opposite side of the lamp filament must be connected to the terminals of the battery. Figure #1 will show the connection with an open switch. If the switch is closed, the circuit will be complete and the lamp will glow as in Figure #2.

Figure #1
Open Switch

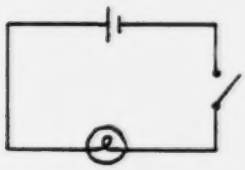
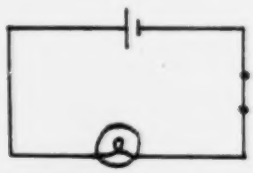


Figure #2
Closed Switch



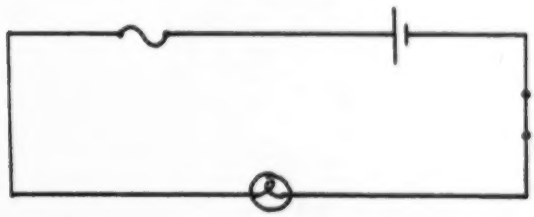
Let the students make the connections in Figures #1 and #2.

B. Procedure: A fuse is a device designed to melt if the current exceeds a specific amount, and therefore, break the circuit before any damage occurs. Let students connect a circuit with a fuse in it as in figure #3.

C. Procedure: A circuit breaker is an electromagnetic switch which serves the same purpose as a fuse. If a fuse burns, it must be replaced, but a circuit breaker can be reset.

Replace the fuse with the circuit breaker; short out the lamp so the breaker is tripped and let students reset circuit breaker. Figure #3 will represent the circuit breaker also.

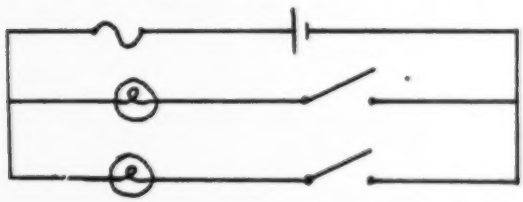
Figure 3
A fuse or circuit breaker in a circuit



D. Procedure: Figure #4 shows how two lamps may be operated from the same battery. Each lamp may be turned on and off independently.

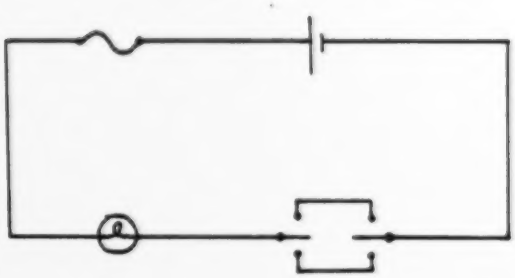
Let students wire the board as in Figure #4 and see that the lamps do operate independently.

Figure #4
Two lamps in a parallel circuit



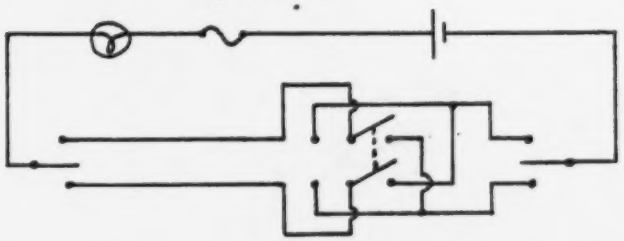
E. Procedure: Three Way Switches: Figure #5 shows a 3-way hookup. This allows a lamp to be turned on and off by two separate switches. Wire the diagram shown in figure #5 and let students observe what happens as each switch is flipped.

Figure #5
3-Way Hookup



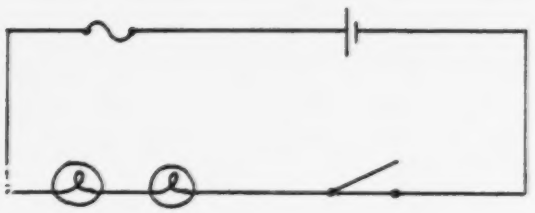
F. Procedure: Four-Way Switches: The diagram in Figure #6 may be used to control a lamp by three different switches. The switch in the middle is a double pole-double throw switch. Wire the diagram in Figure #6 and let students observe what happens as various switches are flipped.

Figure #6
4-Way hookup



G. Procedure: Two Lamps in Series: Figure #7 shows how to wire two lamps in series. Connect this circuit and see if the bulbs glow as before.

Figure #7
Two lamps in series



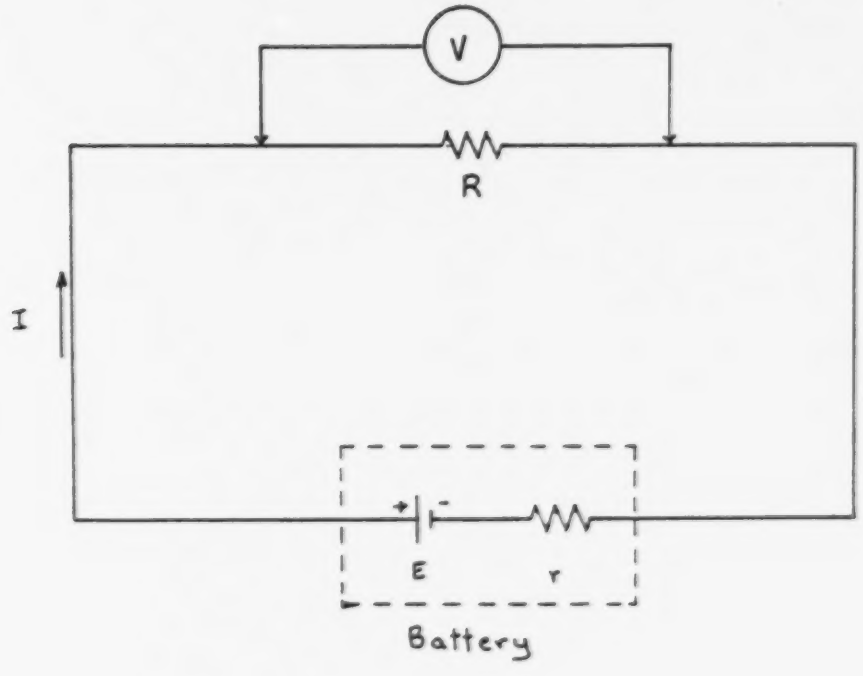
22. INTERNAL RESISTANCES OF BATTERIES (II)

Materials: Several 1.5-V to 6-V batteries, new and used, a resistor of 5 to 20 ohms, an ammeter of known internal resistance (optional), a good voltmeter, preferable a vacuum-tube voltmeter.

Procedure: Connect a battery in series with a resistor, and if available, an ammeter of known resistance Ra. Measure the current. If an ammeter is not available, measure the potential difference across the resistor and calculate the current from $I = V/R$.

Measure the emf of the battery with the VTVM while the circuit is broken. Without an ammeter, the circuit is described by $E = I(R+r)$ where R is the value of the resistor and r is the internal resistance of the battery.

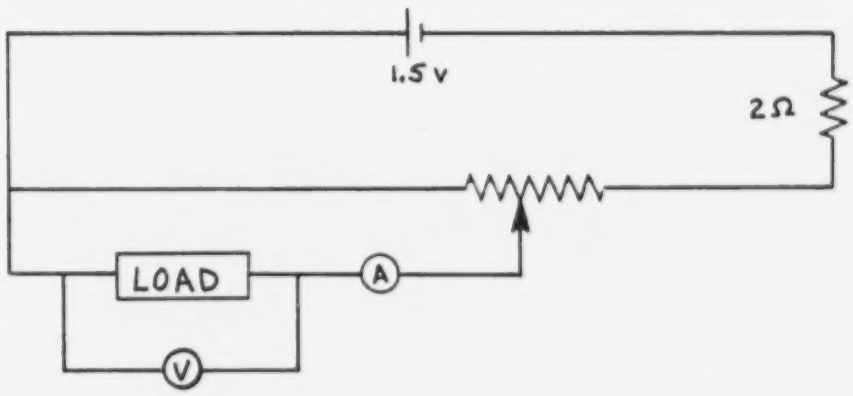
If an ammeter is used, add R_a to R. Determination of E and I Provide suffieient data to calculate r. Battery resistance may vary from 1 or 2 ohms for new batteries to several hundred ohms for old batteries.



23. OHM'S LAW (I)

Purpose: To study the relationship of voltage to current for various conductors. It will be seen that not all conductors obey Ohm's Law.

Materials: A 1.5-volt d.c. source, two 2-ohm resistors, a variable resistor or rheostat voltmeter, ammeter, a diode, a light bulb, connecting wires.



Procedure: Connect the circuit as shown. Several different circuit elements, namely, a 2-ohm resistor, a diode, and a light bulb will constitute the "load." For one of the loads, record the current for different voltages ranging from 0.1 V to 1.5 V. Then reverse the connections to the load so that the voltage will be of opposite polarity and the current will be in the opposite direction. Read voltages and currents again and record these values as negative. Plot the current versus voltage and draw the smooth line that best fits the data points.

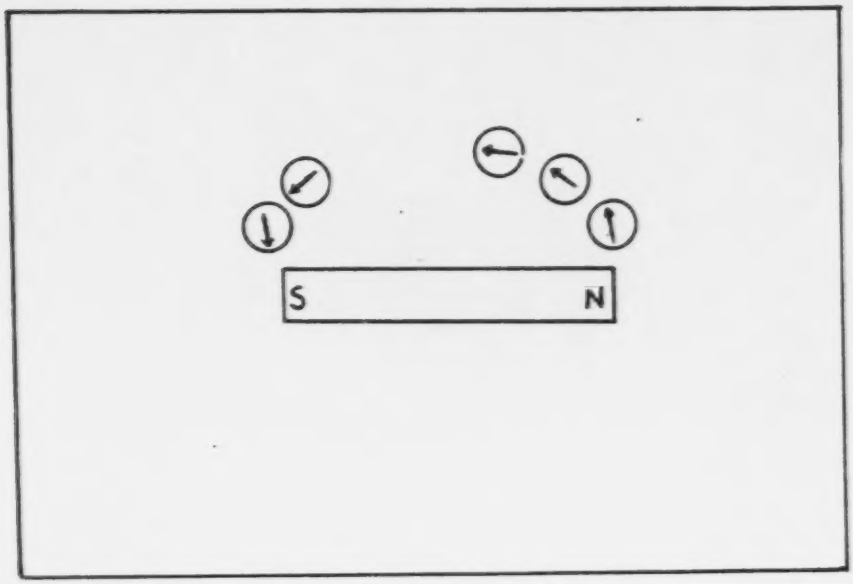
Repeat the procedure for each load.

Ohmic conductors are those that obey Ohm's Law: $V \propto I$, or $V = IR$.

24. PLOTTING MAGNETIC FIELD LINES (I)

Purpose: To use a compass to plot the magnetic field of a bar magnet.

Materials: A bar magnet, a small compass, and a sheet of paper.

Procedure: Place the compass and magnet on the sheet of paper with the compass near the north pole of the magnet. Mark a dot on the paper just outside the compass case in line with the south pole of the compass needle. Place the compass on the dot just made. Continue to move the compass around the magnet and plot the orientation of the compass needle.

Repeat by starting at a different point near the north pole. The lines connecting the points are the magnetic lines of force.